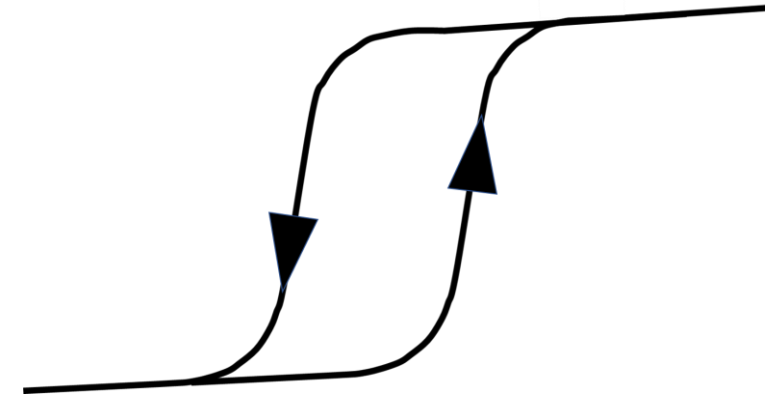# "The Essential Tension":
# Enabling Conditions for Paradigm Shifts in Healthy Enterprise Systems of Innovation

Bill Schindel

Schindel@ictt.com

V1.3.2
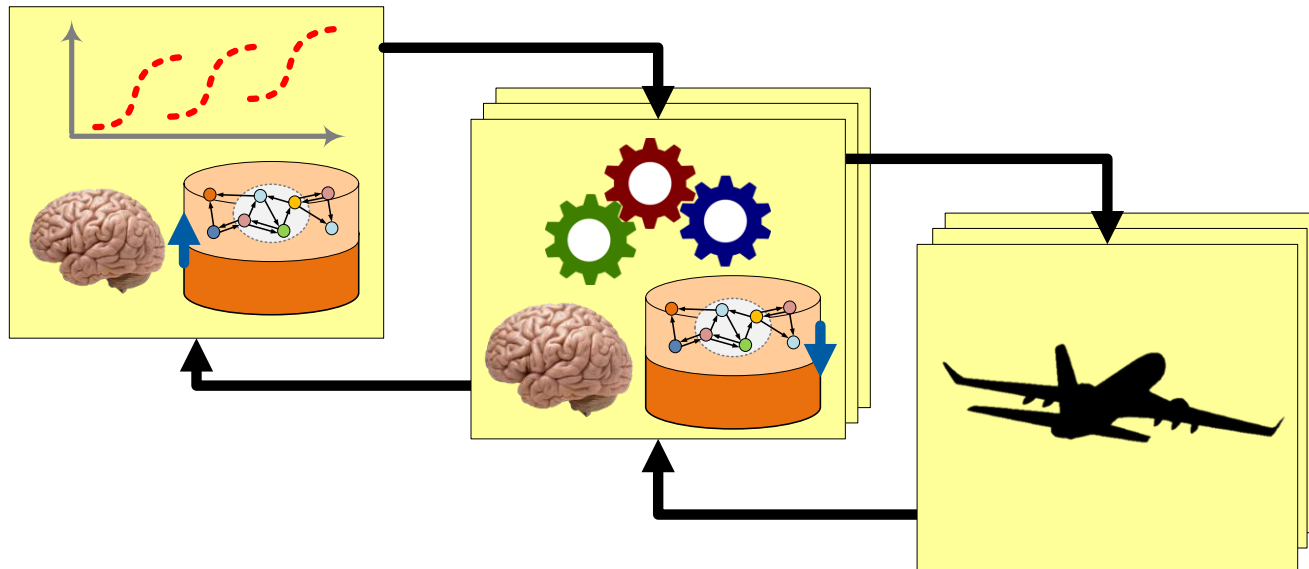
# Acknowledgement
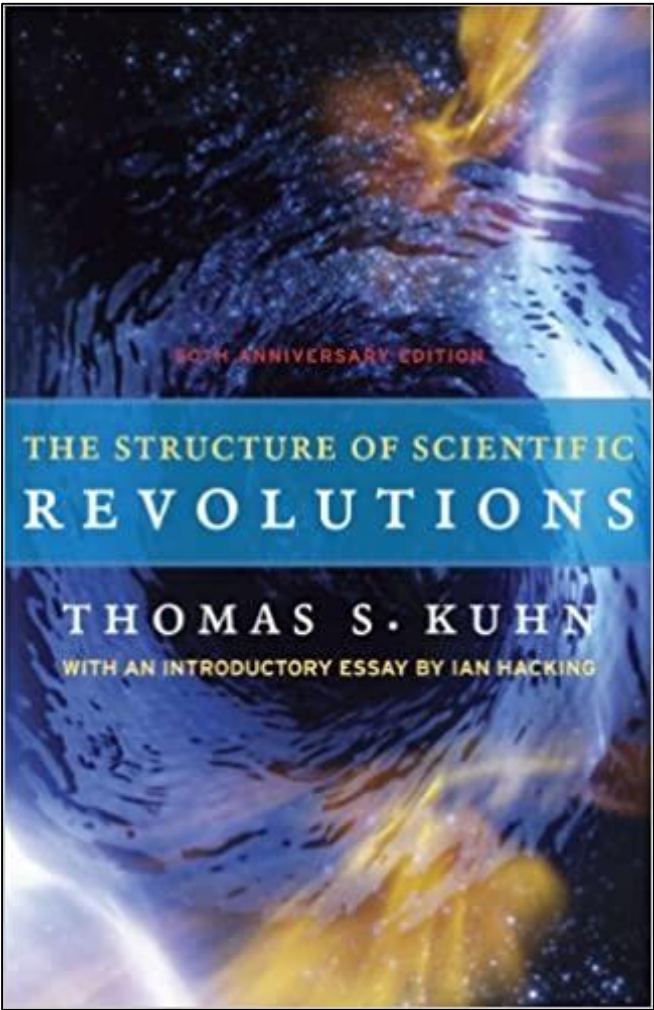
The title on the cover slide is adapted from Thomas Kuhn's book of the same name.
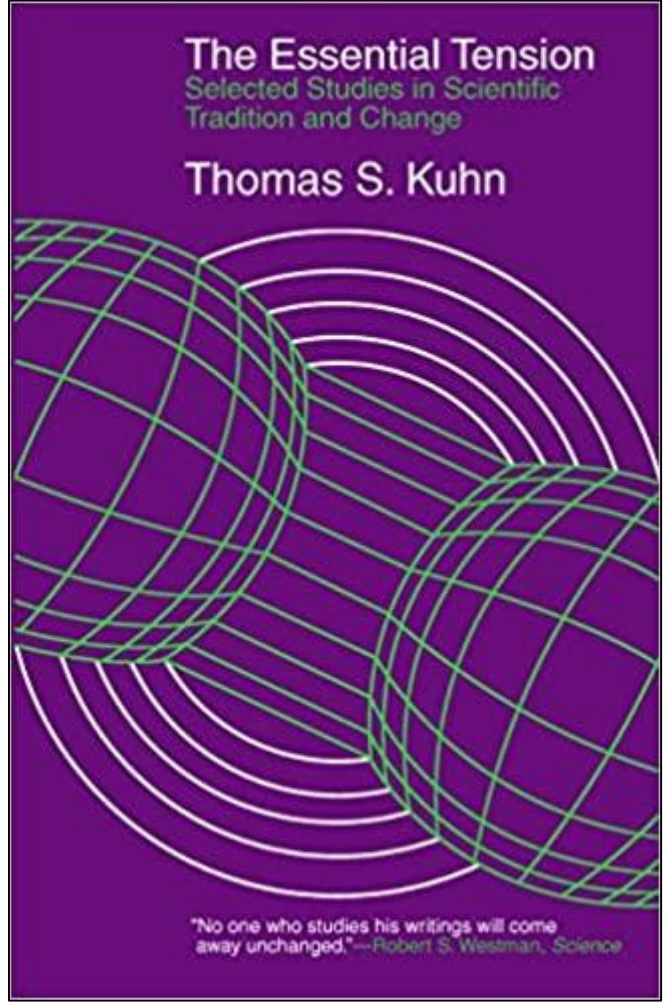
Dr. Kuhn's pioneering studies of human group "paradigm shifts" are directly related to our subject.

Along with these works, Dr. Kuhn's valued past advice is gratefully acknowledged by the author.

T. S. Kuhn, 1922-1996

# Contents

- Briefing Purpose and Scope
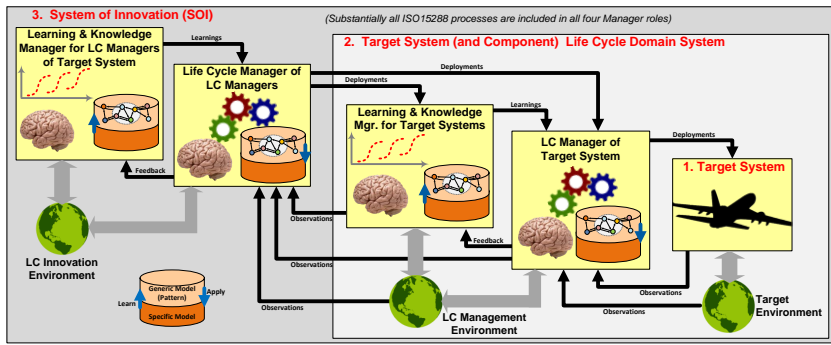
- Abstract

- Strengthened Foundations for Effective Group Learning

- Hysteresis, Learning, and "The Essential Tension"

- Practical Implications for Enterprise Roadmaps

- Discussion

- References

# Briefing Purpose and Scope

- This material summarizes aspects of enterprise level adaptation and change management (INCOSE Agile SE Life Cycle Management [ASELCM]) of the shift to model-based engineering methods and reusable frameworks.

- The technical subjects of those model-based engineering and reusable frameworks, as well as general organizational change management, are not included here (but see the References).

- The following material assumes only limited general awareness of, but not expertise in, model-based engineering knowledge frameworks.

- The purpose here is to improve understanding of how these explicit model-based frameworks improve necessary conditions for successful adoption of sound adaptive methods on a disciplined basis, and incorporation of that understanding into impactful planning roadmaps.
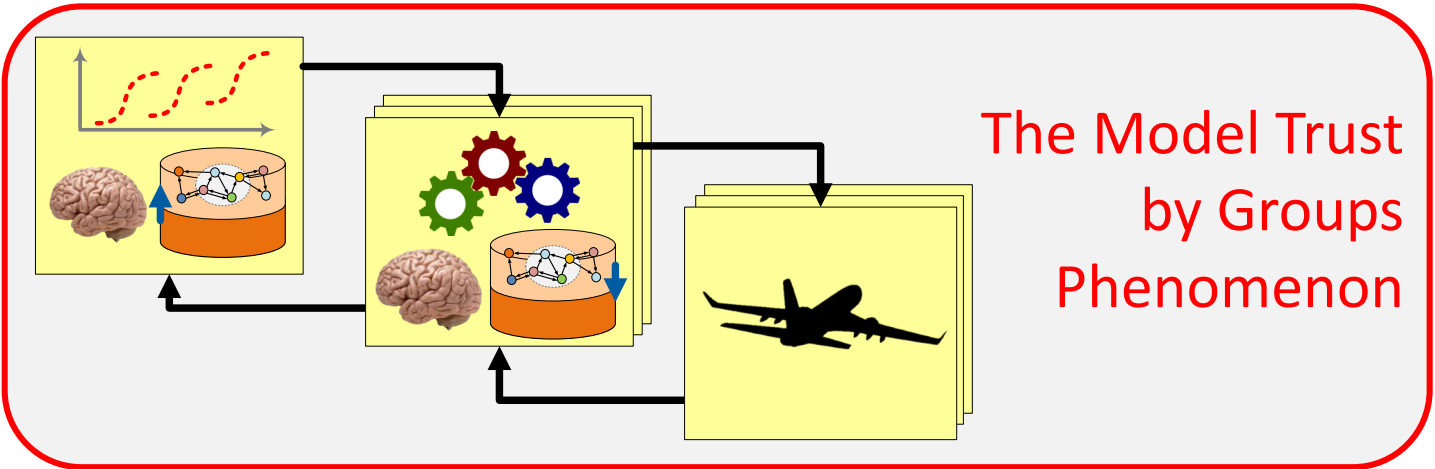
ASELCM System of Innovation Pattern

Hysteresis Curve
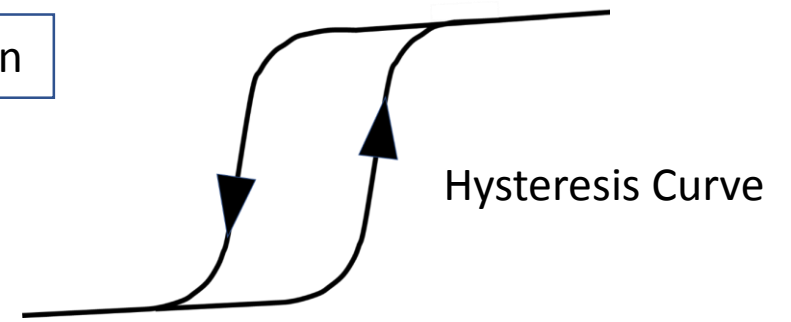
# Abstract

1. The INCOSE Systems of Innovation Pattern is a generic analysis and planning framework that describes _any_ existing or future system of engineering and life cycle management, from the perspective of its _group learning_ capabilities; it is not an engineering method.

2. It can be used to analyze model-based engineering methods, including trusted re-usable general models & frameworks, along with comparison to current methods and ISO15288.

3. The ASELCM INCOSE study reminded us that agile enterprise learning behavior does not mean absence of resistance to change—in fact, such resistance is _essential_ to learning, as Thomas Kuhn reported in _The Essential Tension_.  We also note here another key tension.

4. This leads to recognition that _hysteresis_ is central to effective learning, and certain key conditions that must be present for successful adoption of sound adaptive methods.

5. _Practical roadmaps_ for "Minimum Viable Products" (MVPs) navigating from a current state to future approaches can be described in this way, and these pragmatic plans are supported by insight about _system_-level hysteresis effects, as well as OCM principles.

# Strengthened Foundations for Effective Group Learning

- How groups effectively accumulate knowledge, manage its credibility, apply and share it--at the heart of the <u>Systems Foundation Phenomena</u> efforts by INCOSE.

- Leveraging the foundations of physical science, being used to update the Theoretical Foundations section for INCOSE *Vision 2035*—work already underway a year.



The Model Trust by Groups Phenomenon

1 of the 3 Foundation Phenomena described

INCOSE *Vision 2025* (Current)

Project announced at IW2020

Bill Schindel, ICTT System Sciences, schindel@ictt.com
V2.2.1

INCOSE

Implications for Future SE Practice, Education, Research:
SE Foundation Elements

Discussion Inputs to *INCOSE Vision 2035* Theoretical Foundations Section

(awareness version, 1 hour)          Copyright © 2020 by W. D. Schindel. Permission granted to INCOSE to publish and use.

A WORLD IN **MOTION**
Systems Engineering Vision • 2025

INCOSE *VISION 2035*

*(Theoretical Foundations section, B. Schindel)*

# ASELCM Pattern: Top Level
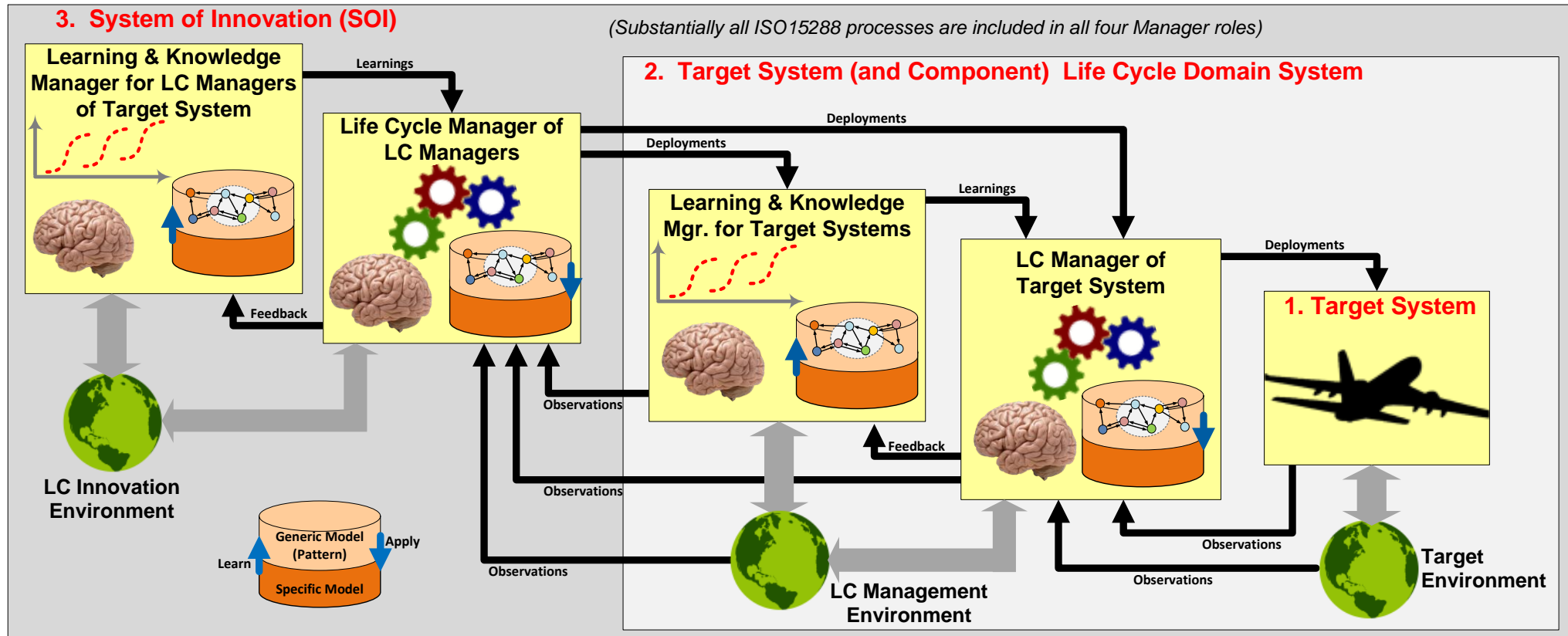


- **System 1**: The Target System to be engineered and managed over its life cycle.
- **System 2**: Environment of System 1, including systems of engineering and life cycle management for System 1. *Responsible for learning about S1 and its environment*.
- **System 3**: Environment of System 2, including systems of engineering and life cycle management for System 2. *Responsible for learning about S2 and its environment*.

# What and whom do we trust?  Managing group learning in both new S1 Products and new S2 Engineering Methods

# System 2: Overview of Virtual Model Creation, Validation, and Utilization

**Digital Twin Pairing**

Includes:
- Screening experiment design
- Model input uncertainty characterization method design
- Model training planning (if applicable—NN case)
- Model testing planning
- Model form uncertainty experiment design
- Propagated model input uncertainties experiment design
- Model numerical uncertainty experiment design

**Real System of Interest** (F)

Experiment Design

(B) (E) Response / Excitation (H) (A1) (A1) (A)

**Experiment Observation Dataset System**
Experiment Observations

**Experiment System** (A)

**Experiment Design System** (A1) (A)

Experiment Design

(B) (E) Model Inputs (C) (E) (G) (E) (C) (E) (D) (E)

**Model Input, Output Dataset System**
Model Observations

**Computational Model System**

**General Model Pattern**

Conceptual Model Hypothesis

**Conceptual Model System**

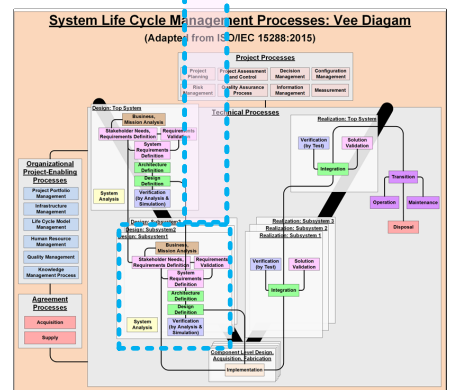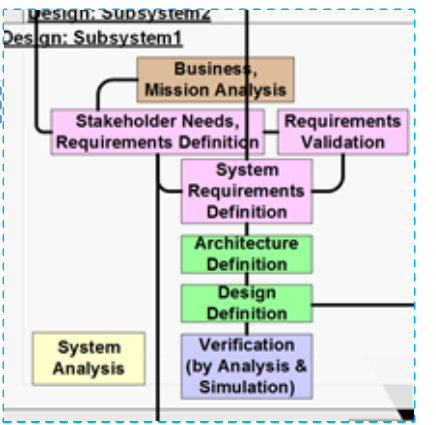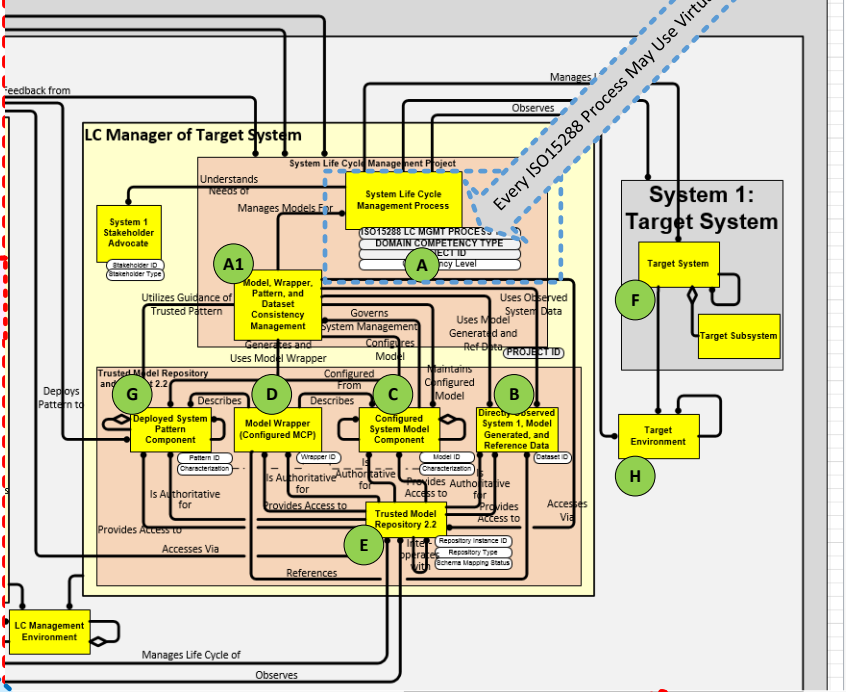**Model Wrapper (Configured MCP Metadata)**

Includes:
- Identification of SOI and SRQ candidates
- Screening of SOI and SRQ candidates
- First principles physical modeling (if applic.)
- Coding, meshing (if applic.)
- Neural network structuring (if applic.)
- Neural network training (if applicable)

Model Training Data
Model Observation Data
Model Test Data
Screening Data

Computational Model Updates
Learned General Pattern
Learning Feedback
Experiment Design
Conceptual Model Hypothesis Updates
Model Requirements

(A1) (A)

**Hypothesis & Model Construction, Update System**

Model Form Uncertainty
Implemented Model
Model SRQ UQ

(A1) (A)

**Model Support for Decision-Making System** (A1)

Model Views and Interpretations
Interpretation of Model Credibility Assessment for Current Use
Decision-Making Requests and Questions

**Model-Supported Decision-Making System** (A)

Model Credibility Assessment

## Model Use

Model Input Data
Model Output Data
Model Test Data
Instrumentation Specs
Assessment Factor Inputs

**Model Credibility Assessment (detail below)** (A1) (A)

---

# System 2: Each ISO15288 Process Can Interact with Virtual Model Data

Feedback from | Manages | Observes

**LC Manager of Target System**

System Life Cycle Management Project

**System Life Cycle Management Process**

Understands Needs of / Manages Models For

ISO15288 LC MGMT PROCESS
DOMAIN COMPETENCY TYPE
PROJECT ID
Proficiency Level

**System 1 Stakeholder Advocate**
Stakeholder ID / Stakeholder Type

(A1) **Model, Wrapper, Pattern, and Dataset Consistency Management** (A)

Governs System Management
Configures Model

Utilizes Guidance of Trusted Pattern

Generates and Uses Model Wrapper

Uses Observed System Data
Uses Model Generated and Ref Data (PROJECT ID)

Maintains Configured Model

Deploys Pattern to

Trusted Model Repository 2.2

(G) **Deployed System Pattern Component**
Describes | Pattern ID / Characterization

(D) **Model Wrapper (Configured MCP)**
Describes | Wrapper ID / Characterization

Configured From

(C) **Configured System Model Component**
Model ID / Characterization

Directly Observed System 1, and Model Generated and Ref Data

(B) **Directly Observed System 1, Model Generated, and Reference Data**
Dataset ID

Is Authoritative for / Provides Access to

Is Authoritative for / Provides Access to

Is Authoritative for / Provides Access to

Provides Authoritative Access to

**Trusted Model Repository 2.2** (E)
Repository Instance ID / Repository Type / Schema Mapping Status

Provides Access to / Accesses Via

References

Inter-operable Unit

**LC Management Environment**

Manages Life Cycle of / Observes

## System 1: Target System

**Target System**
**Target Subsystem**

(F) **Target Environment** (H)

---

# Design: Subsystem2 / Design: Subsystem1

**Business, Mission Analysis**
**Stakeholder Needs, Requirements Definition**
**Requirements Validation**
**System Requirements Definition**
**Architecture Definition**
**Design Definition**
**Verification (by Analysis & Simulation)**
**System Analysis**

Every ISO15288 Process May Use Virtual Models

---

**System Life Cycle Management Processes: Vee Diagram**
(Adapted from ISO/IEC 15288:2015)

## ISO15288 Processes ("Vee Diagram") – Basis of the INCOSE SE Handbook

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# Model Credibility Assessment

## SRQ Uncertainty Quantification

From Roy & Oberkampf, A comprehensive framework for verification, validation, and uncertainty quantification in scientific computing, retrieve from: http://ftp.demec.ufpr.br/disciplinas/TM798/Artigos_seminario/roy_oberkampf_2011-verification.pdf

Model Input Data | Instrumentation Specs | Model Output Data | Model Test Data | Implemented Model

**Characterize Input Uncertainties**
Model Inputs Uncertainty

**Generate Model Form Uncertainty**
Model Form Uncertainty

**Propagate Input Uncertainties Through Model**
Propagated Uncertainties, As P-Box

For example:
- Area Metric (Human-Est)
- BNN Uncertainty (Machine-Est)

**Estimate Numerical Uncertainties**
Estimated Numerical Uncertainty

Typical CAF factors may include:
- Context of Use (COU)
- Criticality of Decision
- Impact of Model on Decision
- Experience of Modeling Team
- Experience with Model
- Other factors

**Expand Model Form Uncertainty p-box Sides Using Propagated Uncertainty P-Box**

**Expand p-box Sides Using Numerical Uncertainty P-Box**

**Credibility Assessment Framework Set Up**

**Expand p-box Sides Using Model Extrapolation Uncertainty P-Box**

**Credibility Assessment Framework Valuation**

CAF
Assessment Factor Inputs
Model SRQ UQ
Model Credibility Assessment

## Virtual Model Credibility Assessment-- including Model Verification, Validation, Uncertainty Quantification (VVUQ)

---

# System 3

(A) (A1) **Project Management**

**Deployed Project Pattern (for Computational Modeling)** (G)

**Configured Project Pattern & Status (for Computational Modeling)** (C)

**Directly Observed System 2 Performance Data** (B)

## System 3:
Configures Project from Learned Pattern, Tracks and Controls Project, "Scores" Project Performance, Learns More

---

## 3. System of Innovation (SOI)

**Learning & Knowledge Manager for LC Managers of Target System**

**Life Cycle Manager of LC Managers**

**LC Innovation Environment**

## 2. Target System (and Component) Life Cycle Domain System

(Substantially all ISO15288 processes are included in all four Manager roles)

**Learning & Knowledge Manager for Target Systems**

**LC Manager of Target System**

**1. Target System**

**LC Management Environment**

**Target Environment**

Deployments / Observations / Feedback

## INCOSE ASELCM Pattern – Virtual Learning Ecosystem Framework

From Schindel & Dove, Introduction to the ASELCM Pattern, INCOSE 2016 International Symposium, retrieve from https://www.omgwiki.org/MBSE/lib/exe/fetch.php?media=mbse:patterns:is2016_intro_to_the_aselcm_pattern_v1.4.8.pdf

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Populates | Populates | Populates | Details | Details | Details

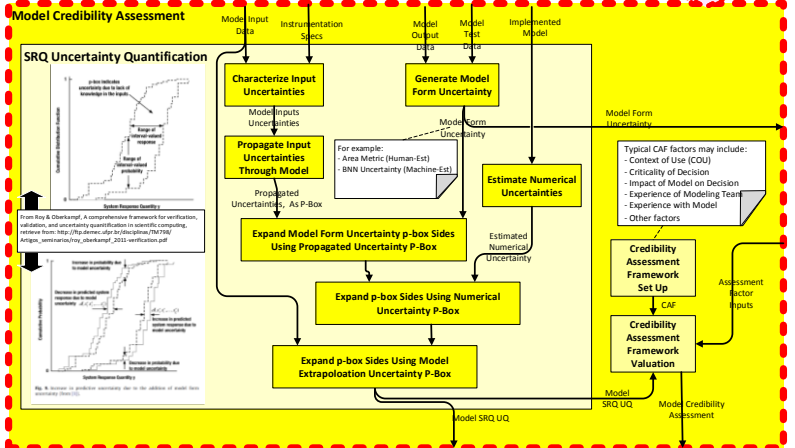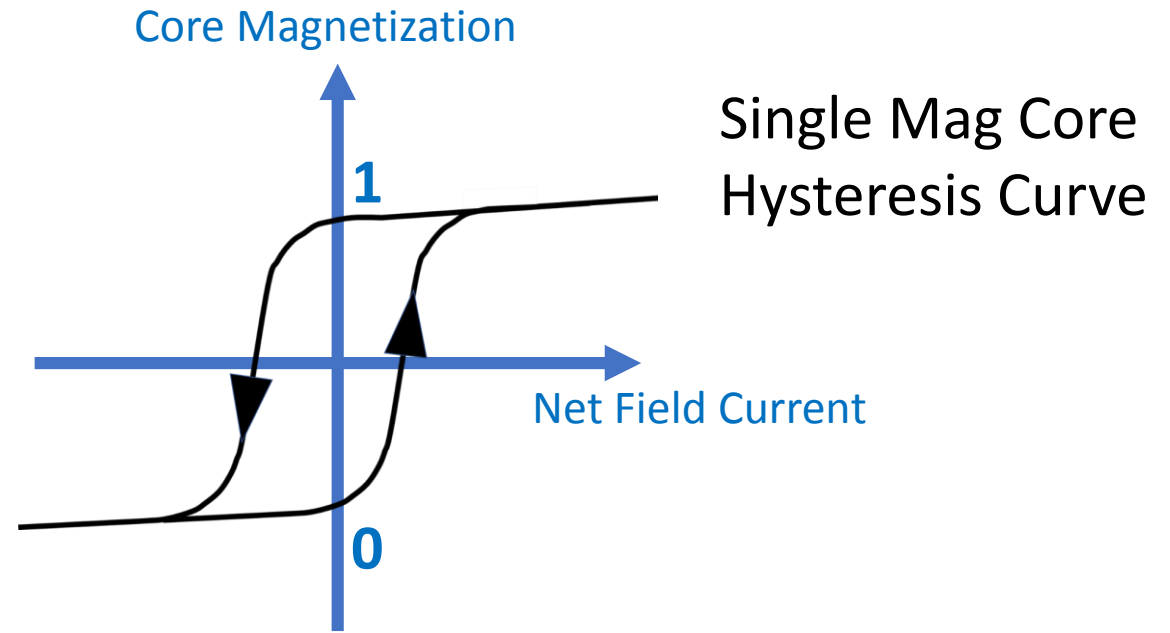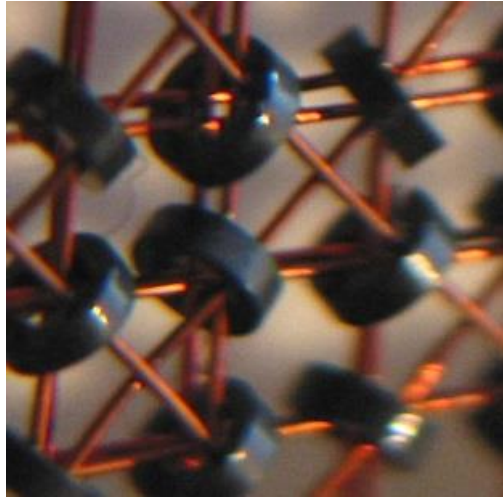Decision-Making of Every ISO15288 Process May Use Virtual Models

Every ISO15288 Process May Use Virtual Models

System 2, System 1

**Practical management of model credibility—from top to bottom.**

# Hysteresis, Learning, and "The Essential Tension"



Magnetic Core Memory Plane

Core Magnetization

Single Mag Core Hysteresis Curve

1

0
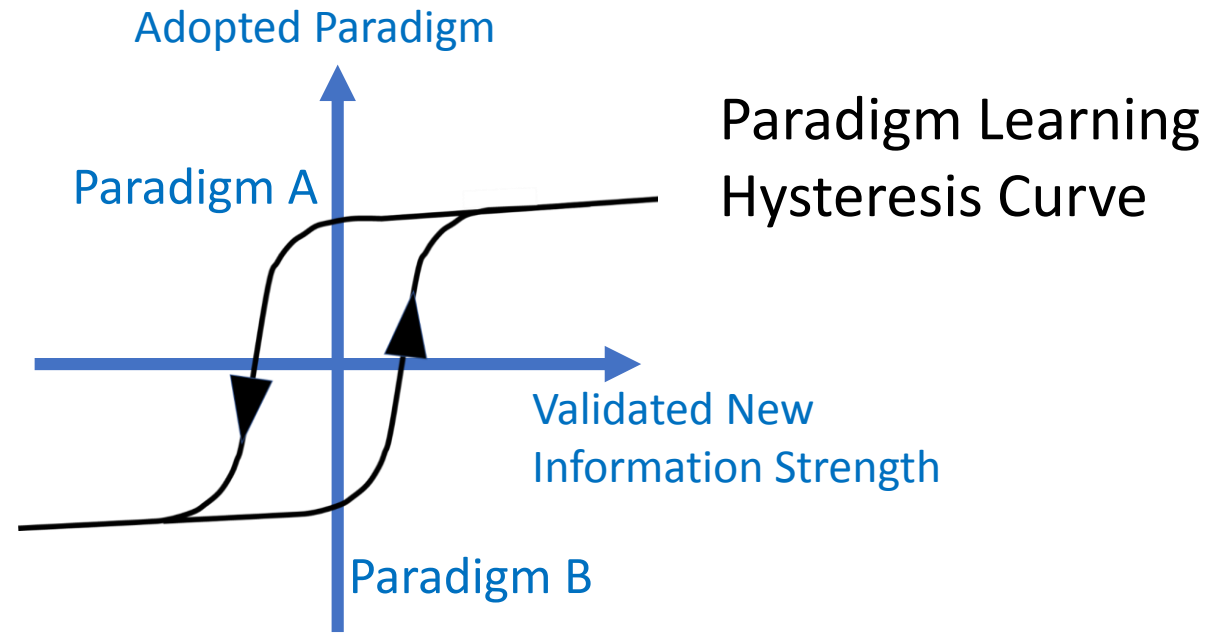
Net Field Current

- A simple magnetic core 1 bit memory illustrates <u>hysteresis</u> essential to effective memory/retention.

- Its non-linear behavior guarantees a degree of needed stability: A core "stays" set at "0" or "1" until a <u>sufficient</u> future current flips it to the other state.

- Likewise, a human "learning" a lesson should be able to use that learning the next day: If "too agile", every passing day may result in different behavior, so there is not enough stability to effectively accumulate and apply knowledge.

# Hysteresis, Learning, and "The Essential Tension"



Practicing Engineer

Adopted Paradigm

Paradigm A

Paradigm Learning Hysteresis Curve

Validated New Information Strength

Paradigm B

- The very term "discipline" implies a degree of stable behavior in the face of new signals and disturbances.

- *However*, if learning requires such stability in what is learned, then what should it take to "change our mind" later when a new learning opportunity occurs?

- *This is Kuhn's "essential tension"*: Simultaneous ability to be open to sufficiently validated new information, while at the same time sufficiently resistant to change to assure disciplined "in paradigm" performance. (Also applies to methods!)

# Hysteresis, Learning, and "The Essential Tension"
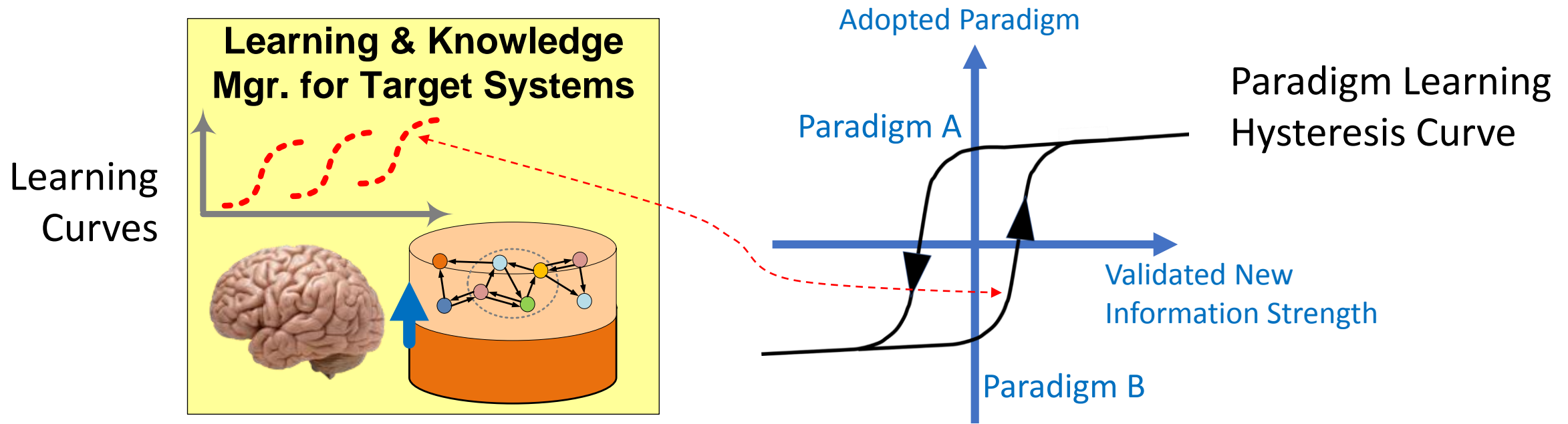


- This is also where the INCOSE SE Foundations Project (see the INCOSE Patterns Working Group) connects to historical math/science platforms:

  - Bayesian Science—how do we optimally mix what we already know with new learning?

  - Model VVUQ—what does traditional quantitative model validation in the physical sciences teach us about math and science of model credibility?

  - Credibility Assessment Frameworks—what about the other, more subjective aspects of awarding our trust to a model?

  - System Level Hysteresis—what does The System Phenomenon tell us about systemic paradigms? About resilient recovery of previous system states in critical infrastructure system recovery?

# Model Credibility Assessment Frameworks (CAFs)

- Generalized tree-based framework for describing why anyone (or any team or enterprise) has awarded a degree of trust in a model.
- Used by US NRC and other entities.
- Built into the  Model Characterization Pattern (MCP, or "Model Wrapper")
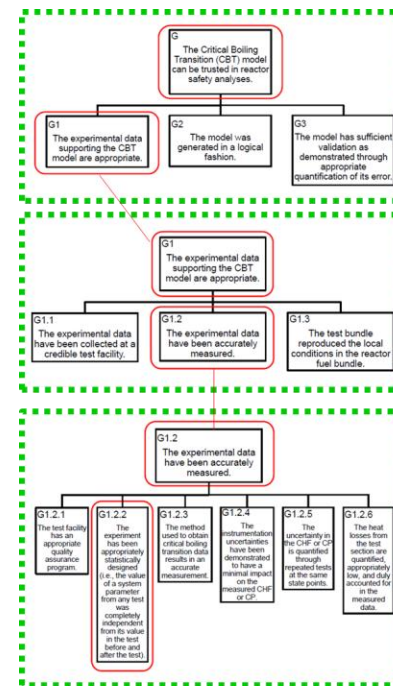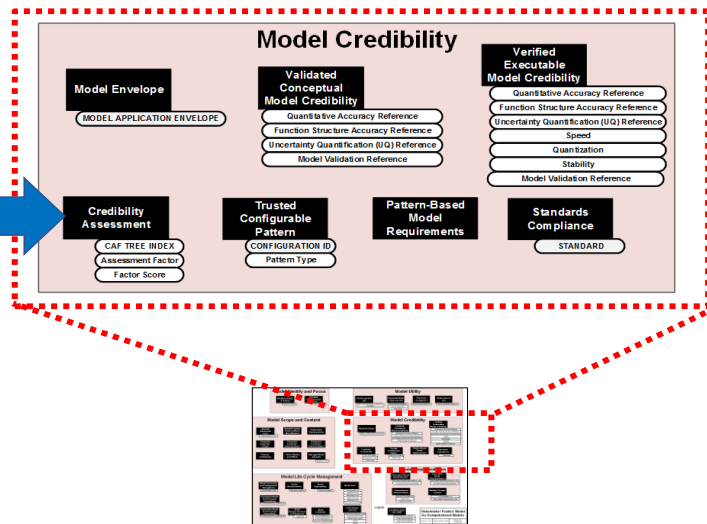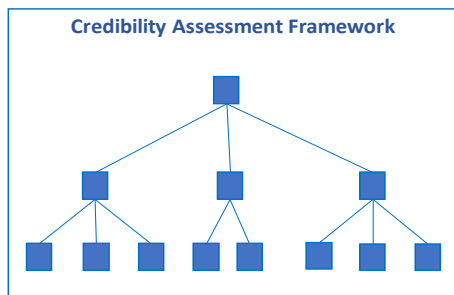


Credibility Assessment Framework Example

Adapted from Kaizer, Joshua, "Credibility Assessment Frameworks", https://cstools.asme.org/csconnect/FileUpload.cfm?View=yes&ID=54674

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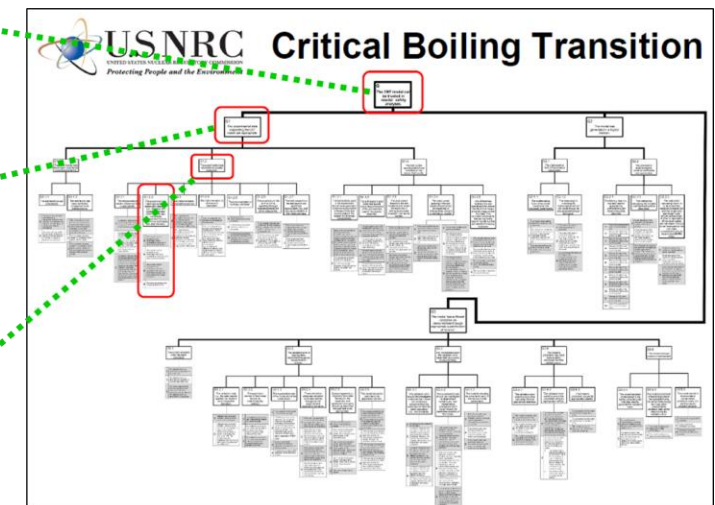
# Hysteresis, Learning, and "The Essential Tension"
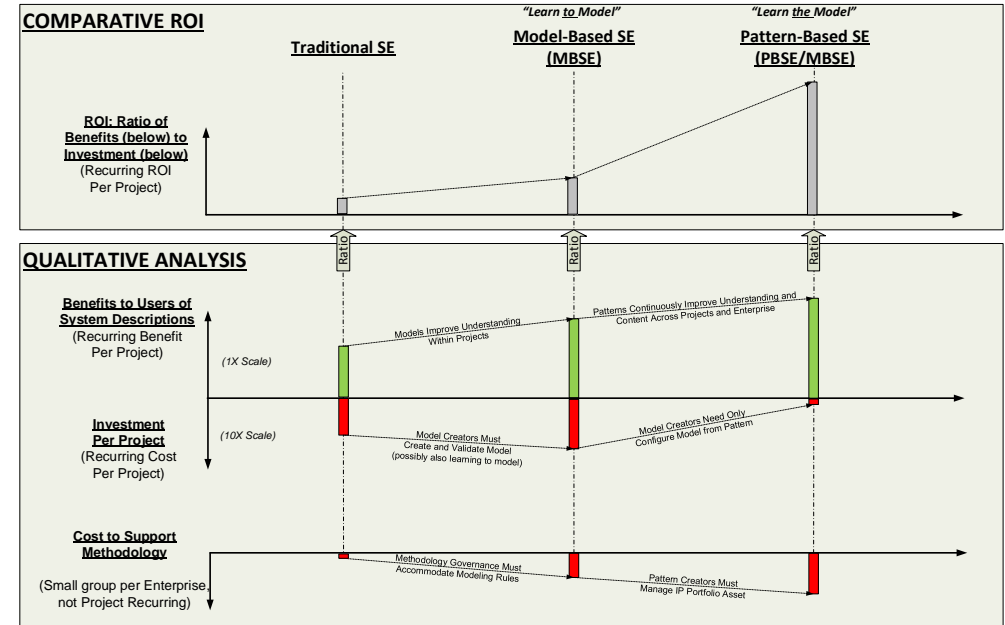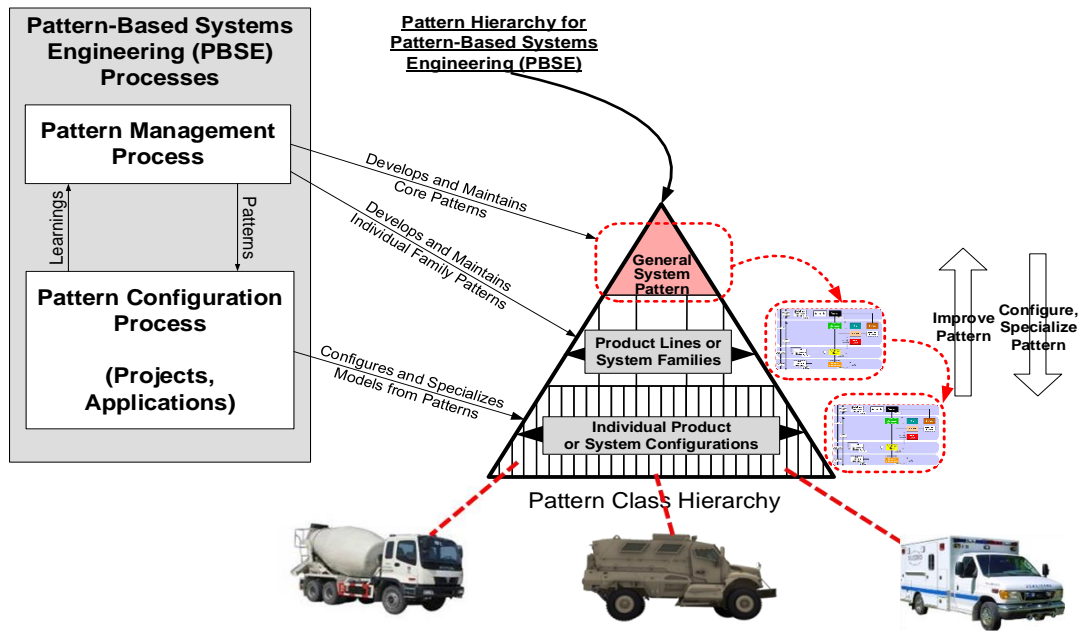


- Kuhn mentioned in passing the additional "Essential Tension" aspect which is the main focus of work of the INCOSE MBSE Patterns Working Group:
  - **Individuals vs. Groups**: How to optimize the shared use of what "we" already know, versus what "I" already know—across the Enterprise, Supply Chain, Regulated Domain, Society.
- Implications for centralization versus distribution of Engineering—related sharing strategies in both cases.
- Start up of collaboration with Indiana University's Ostrom Workshop on The Commons—fruit of 50 years, Elinor Ostrom's related Nobel Prize in Economics.

- Pattern data as IP, and a proxy for group learning:
    - Information Debt, not just Technical Debt, as a foundation of adaptive, agile innovation.
    - Patterns can be capitalized as financial assets under FASB 86.
- "Patterns as capital" changes the financial logic of project level SE "expense"
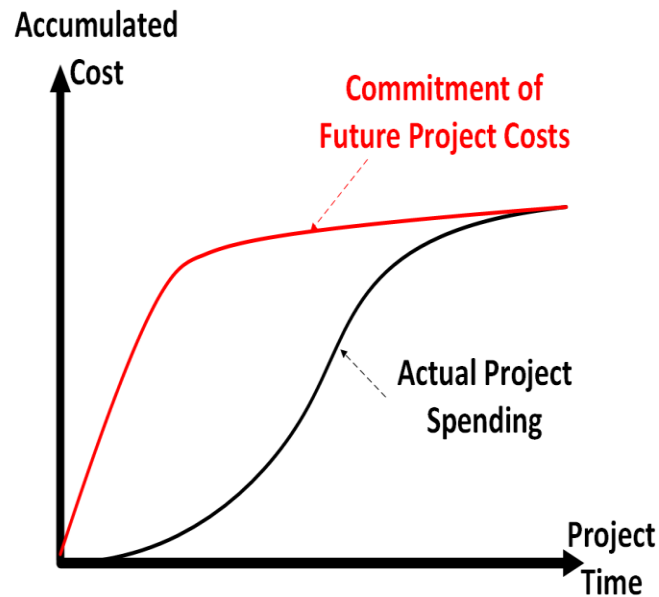


(a) When Project Costs Are Committed versus Incurred
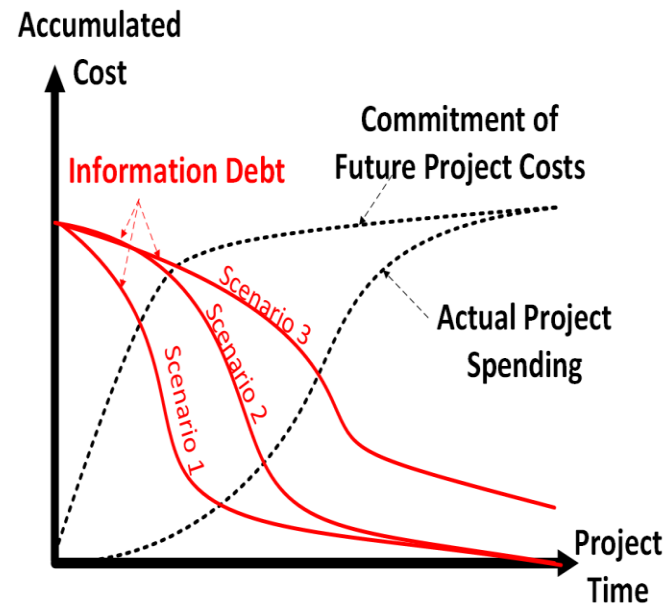
(b) Information Debt is Reduced Over the Course of Project
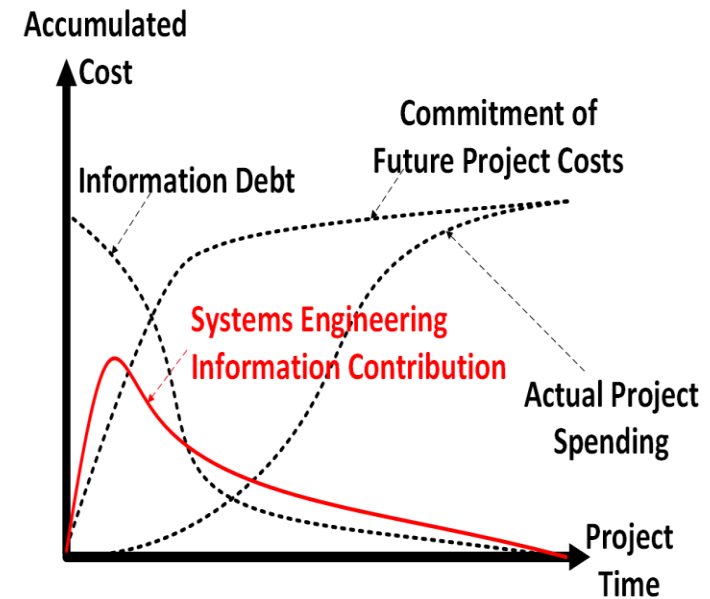
(c) Systems Engineering Information Is Generated to Reduce Information Debt

From Dove, Garlington, and Schindel, "Case Study: Agile Systems Engineering at Lockheed Martin Aeronautics Integrated Fighter Group", from *Proc. of INCOSE 2018 International Symposium*, 2018, Washington.

# Where are the Incentives? For whom?

- *__If__* we assume the incentives for sharing information must be to individuals, then the asymmetry of incentives to the individuals involved should be considered:
    - Testimony of engineering staff who would like it to be easier to find out about existing model assets they could trust to use;
    - Concerns whether some engineering staff may feel that sharing their models with others may not be in their interest, versus others who feel it is a way for their work to have greater impact.
- The engineering process produces and consumes information.
- So, there are in all cases information producers and consumers.
- Must the information content be generated in advance?
- Our experience is somewhat different:
    - Generating reusable patterns concurrent with projects
    - Packaging pre-existing enterprise assets in more accessible "wrapped packages", using the Model Characterization Pattern (MCP).
- Questions we also heard about whether new things need to be learned or additional work performed during an already stressed effort time  . . .
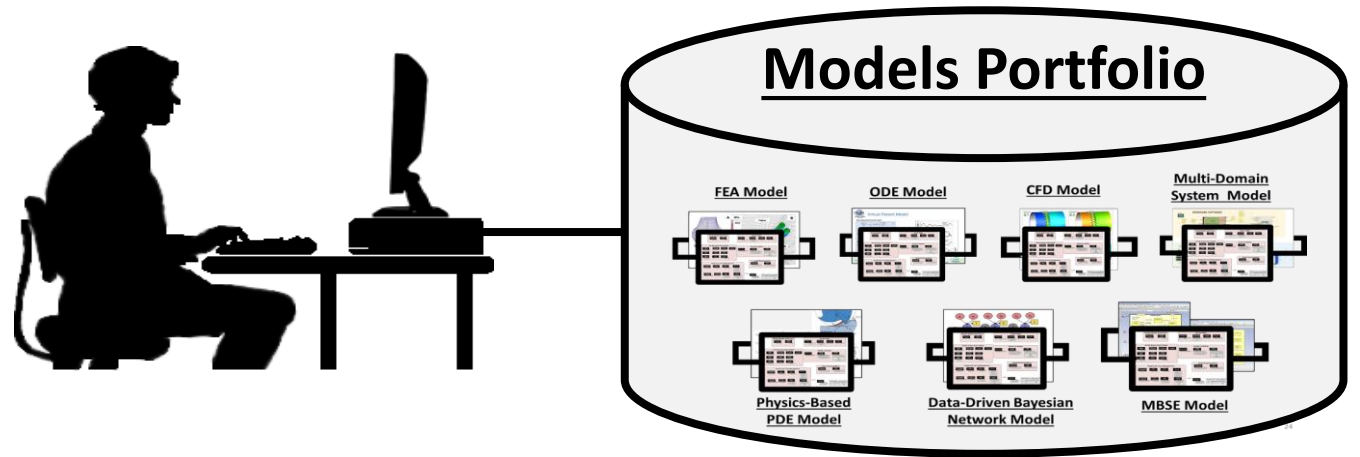
# Related Constructs

- Model Characterization Pattern (MCP) (AKA "Model Wrapper"):
  - Metadata that characterizes (models) any virtual model of interest, of any type (FEA or CFD simulations, MBSE models, Systems Dynamics Models, data-driven Neural Network models, etc.).
  - Becomes a universal label (wrapper) for managing large libraries of disparate models, as well as understanding intent, credibility and provenance of any model.
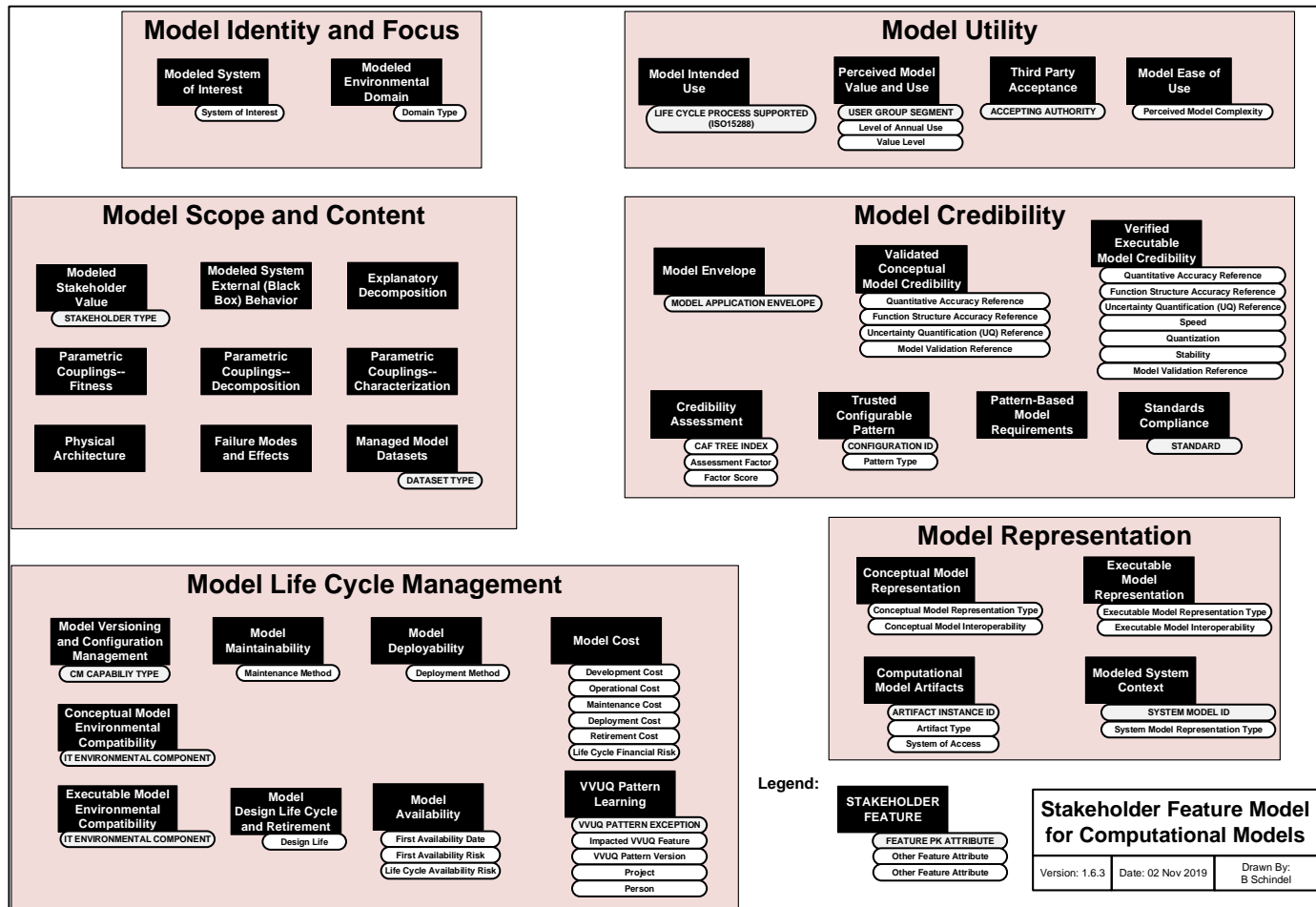




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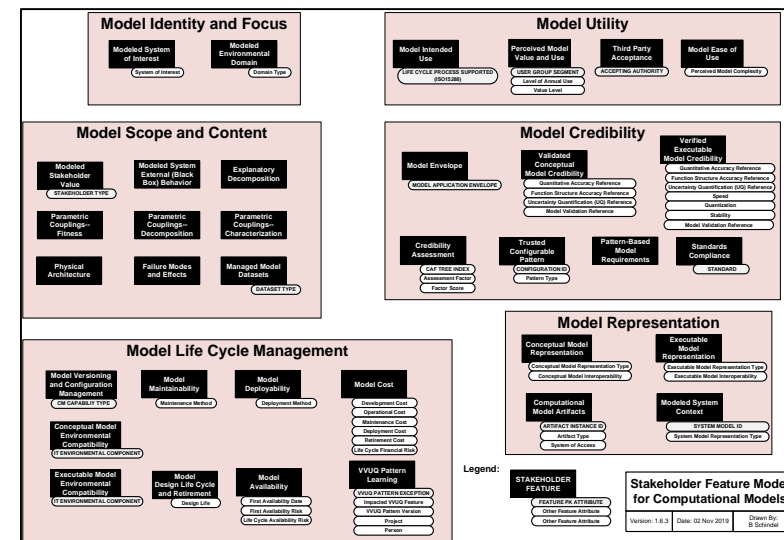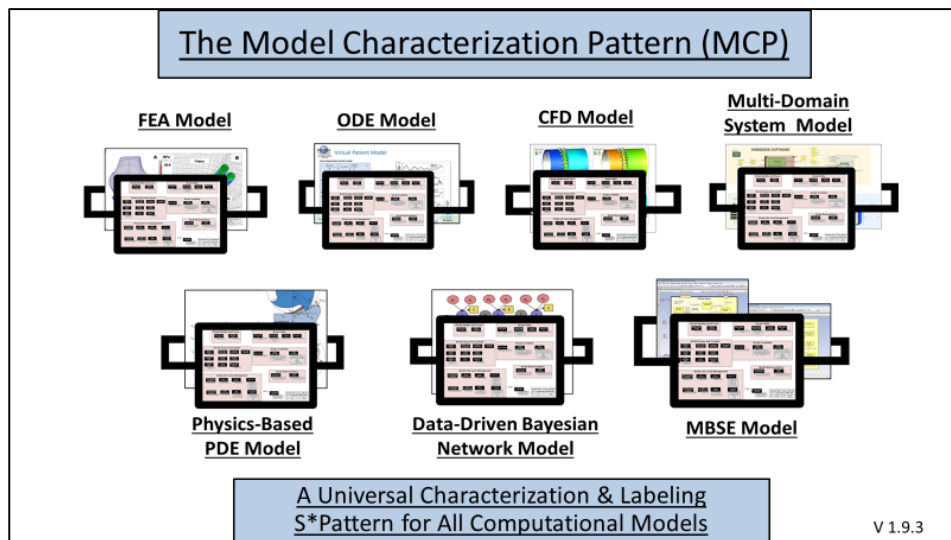
# Building Wrapper Metadata

- Does not need to be done in advance, . . .

- But also consider priming the pump by wrapping model content you or supply chain already have, if it provides value to stakeholders.



**Models Portfolio**

FEA Model    ODE Model    CFD Model    Multi-Domain System Model

Physics-Based PDE Model    Data-Driven Bayesian Network Model    MBSE Model



FEA Model    ODE Model    CFD Model    Multi-Domain System Model

Physics-Based PDE Model    Data-Driven Bayesian Network Model    MBSE Model



FEA Model    ODE Model    CFD Model    Multi-Domain System Model

Physics-Based PDE Model    Data-Driven Bayesian Network Model    MBSE Model

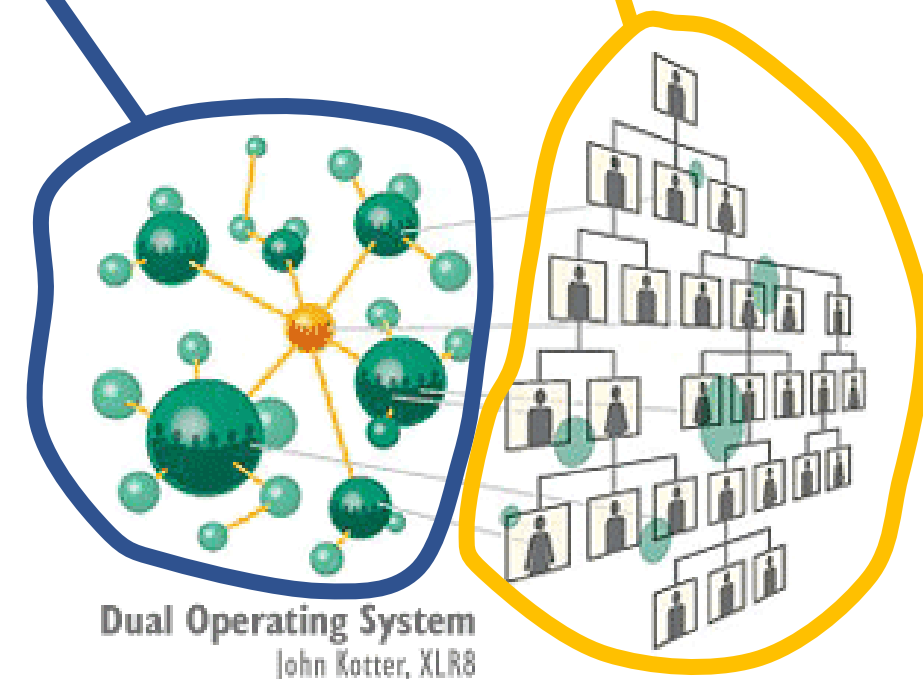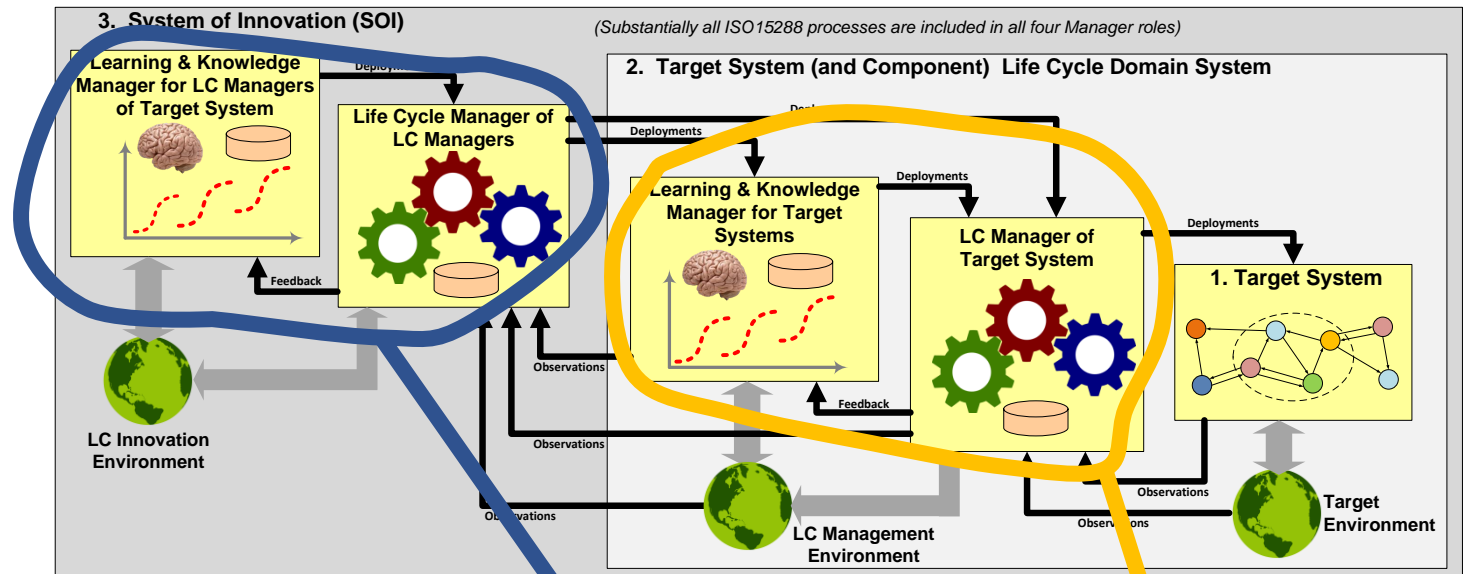# Domain Specific Language Patterns: Learning the "TV Guide Menu"





- How to search, select models.

- Model Wrapper describes features of any virtual model of any type.

- Basis for model library management, organizing model ecosystem across supply chains.

- Learning the TV control buttons and the guide menu structure: required to search for and select TV shows.

- Similarly, learning the language of an engineering domain is expected to work in that domain—same is true for each domain pattern (e.g., gas turbines, medical devices, etc.)

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# Practical Implications for Enterprise Roadmaps

- Whatever strategy is selected, it can be very effectively represented using the ASELCM Pattern, as agile release trains of deltas to S2 Features, Roles, and Design Components—such a roadmap should be generated in any case.
- This also encourages creation of "internal markets" that help power what follows with energy and resources. You cannot push on a rope.
- We always recommend this order of precedence:
  - Information first
  - Process second
  - Automation last
- Accordingly, we suggest defining some of the "MVP's" to not require automation, but information.
- We suggest creation of S1 or S2 patterns through UTP activities that are part of, not in advance of, application projects/programs.
- Pay attention to the literature on general OCM, and in particular Kotter . . .

(Kotter 2014)

- System 3 is directly related to Organizational Change Management (OCM) for transformation.
- System 3 and 2 together reflect John Kotter's "dual operating system" approach to leading change. (Kotter 2014) (Think of logical <u>roles</u>, in some case performed by same physical <u>people</u>.)
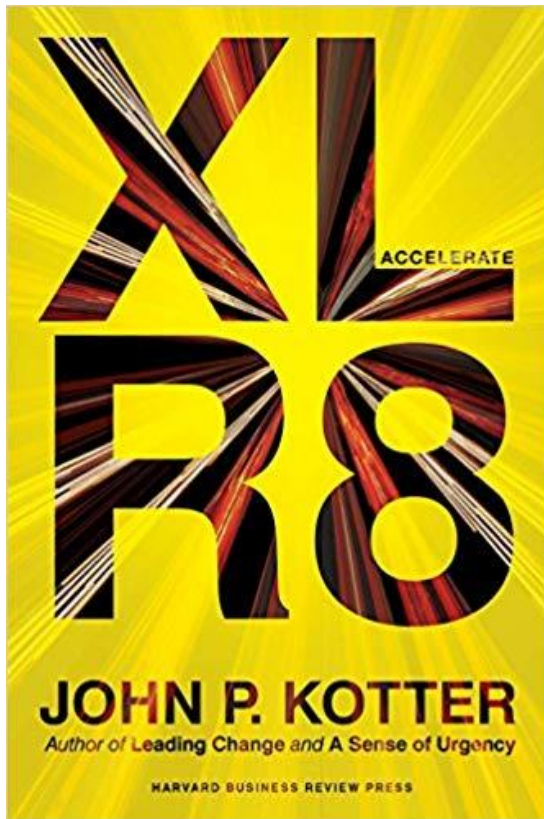
Dual Operating System
John Kotter, XLR8

# Discussion

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# References

1. INCOSE MBSE Patterns Working Group web site: https://www.omgwiki.org/MBSE/doku.php?id=mbse:patterns:patterns

2. Theoretical Foundations materials in process for INCOSE *Vision 2035* Project: https://www.omgwiki.org/MBSE/lib/exe/fetch.php?media=mbse:patterns:science_math_foundations_for_systems_and_systems_engineering--1_hr_awareness_v2.2.1_wide_fmt.pdf

3. Introduction to the INCOSE ASELCM Pattern: https://www.omgwiki.org/MBSE/lib/exe/fetch.php?media=mbse:patterns:is2016_intro_to_the_aselcm_pattern_v1.4.8.pdf

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5. Kotter, J. *Accelerate: Building Strategic Agility for a Faster-Moving World*. Harvard Business Review Press, Cambridge, MA. 2014.

6. Indiana University Ostrom Workshop: https://ostromworkshop.indiana.edu/

7. Frank van Laerhoven , Michael Schoon, Sergio Villamayor-Tomas. "Celebrating the 30th Anniversary of Ostrom's *Governing the Commons*: Traditions and Trends in the Study of the Commons, Revisited". *International Journal of the Commons*. 27 Feb, 2020. Retrieved from: https://www.thecommonsjournal.org/articles/10.5334/ijc.1030/