MBSE Patterns in the Public Square:

Public, Private, and Hybrid Leverage

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Abstract

MBSE Patterns have been applied over the years across a variety of domains, in advanced manufacturing, automotive, telecommunication, medical/health care, mil/aerospace, and other domains. MBSE Patterns describe recurring system situations using system models, including stakeholder fitness spaces and markets, required behaviors, design solution families, platforms, and product lines, risks and failures, and other aspects. Because of this recurring nature, these MBSE Patterns are attractive to use <u>within an enterprise</u>, but for the same reason are also attractive <u>across enterprises</u>, to describe shared industry domain frameworks for supply chains, standards or practices, other system subjects that must be communicated across different enterprises, institutions, government agencies and authorities.

Abstract, continued

Commercial enterprises and defense agencies naturally want to protect enterprise or national Intellectual Property (IP), but also have an interest in other cases that descriptions be shared or even public agreements. So, given these interests in Patterns in Private and Patterns in the Public Square, how do we navigate the challenges of reaching agreement on and sharing public or shared content while clearly protecting private or proprietary value, and how can these two interests be managed within the framework of a single product, system, product line, or domain? This talk will explore these issues in more detail, including how model-based methods help answer these otherwise challenging questions. Brief case examples will be included.

Contents

The INCOSE MBSE Patterns Working Group, part of the INCOSE/OMG MBSE Initiative, pursues the discovery, expression, and exploitation of re-usable, configurable MBSE models, called S*Patterns:

- http://www.incose.org/ChaptersGroups/WorkingGroups/transformational/mbse-patterns
- http://www.omgwiki.org/MBSE/doku.php?id=mbse:patterns:patterns


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MBSE Patterns Working Group

Mission & Objectives

The mission of the INCOSE MBSE Patterns Working Group is to advance the availability and awareness of practices and resources associated with the impactful creation, application, and continuous improvement of MBSE Patterns over multiple system life cycles. The practice of MBSE using System Patterns is also referred to as Pattern-Based Systems Engineering (PBSE).

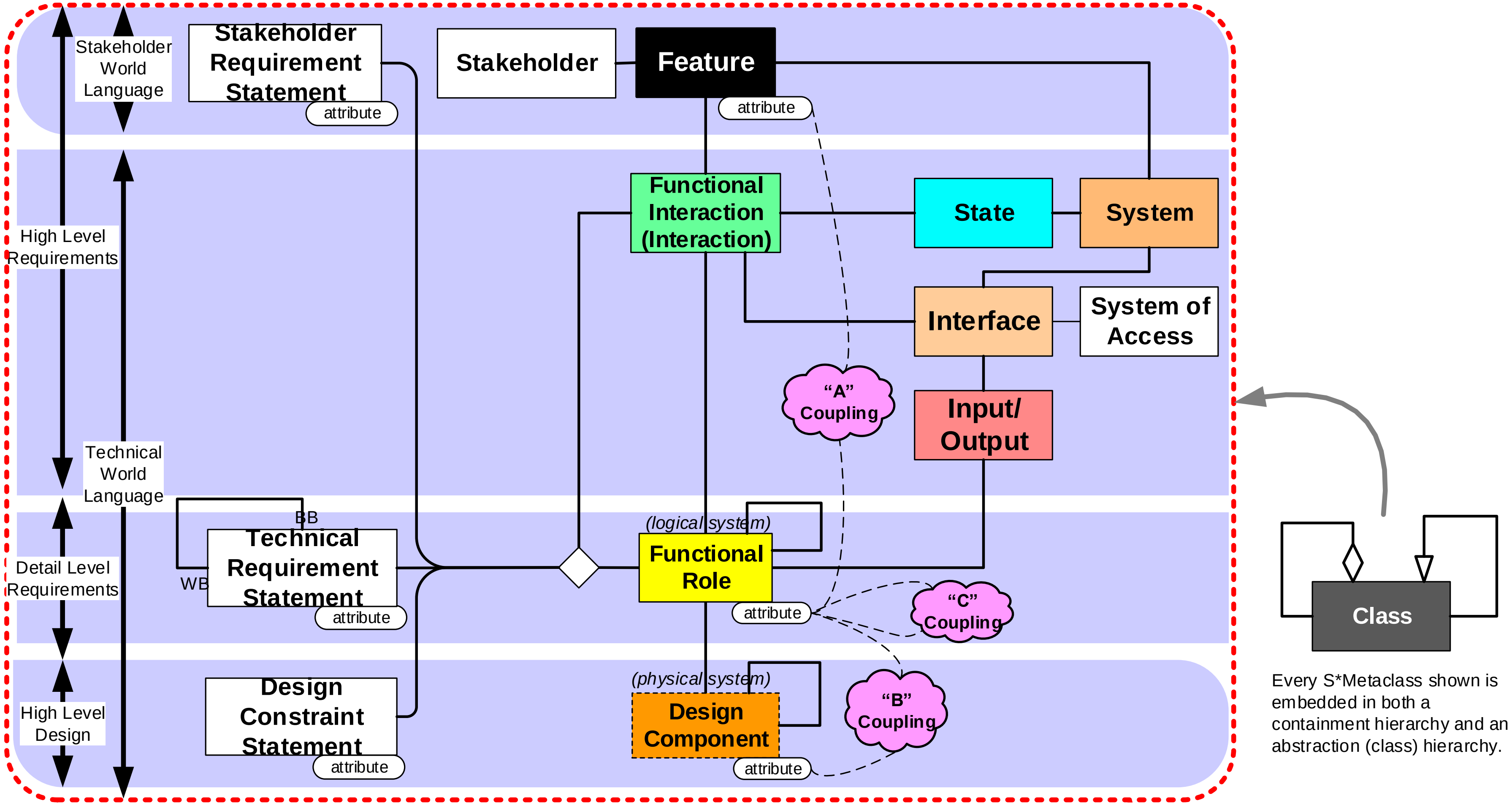
This Working Group is a 2016 re-chartering of the former INCOSE MBSE Patterns Challenge Team, originally chartered in 2013 as a part of the INCOSE MBSE Initiative, which it continues to closely support. This Working Group Charter's closely follows the original Challenge Team Charter, updated in 2016 to mark the INCOSE organizational re-classification of this Challenge Team as a Working Group, while continuing the general mission of this historically active team.

As used here, System Patterns are configurable, re-usable System Models that would otherwise be like those expected and

S*Metamodel: The smallest underlying framework of ideas found over the years to be necessary for practice of engineering and science:

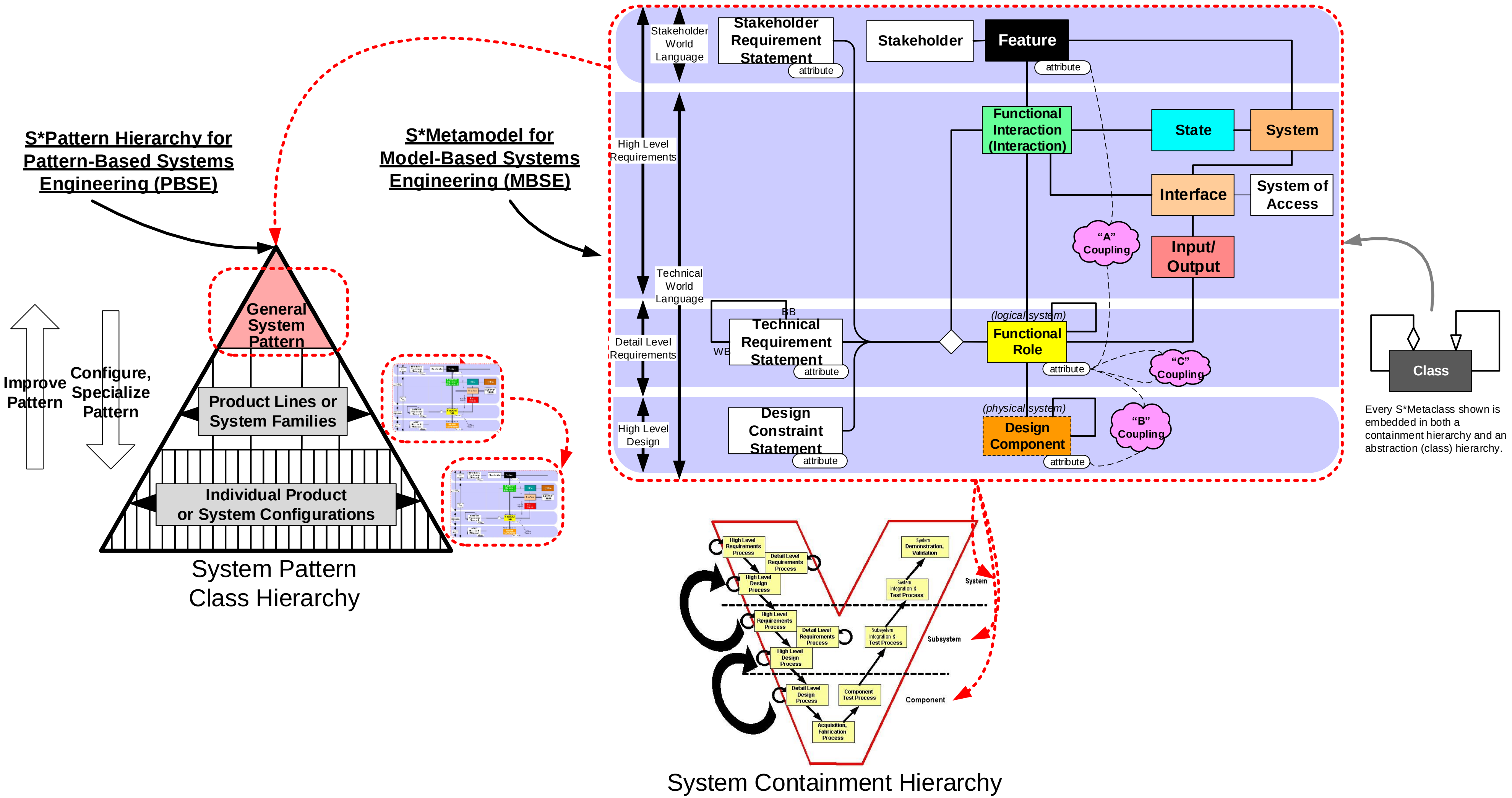
Independent of specific modeling languages or tools, but has been mapped into the popular contemporary modeling and engineering toolsets and modeling languages.

S*Metamodel for Model-Based Systems Engineering (MBSE)



Every S*Metaclass shown is embedded in both a containment hierarchy and an abstraction (class) hierarchy.

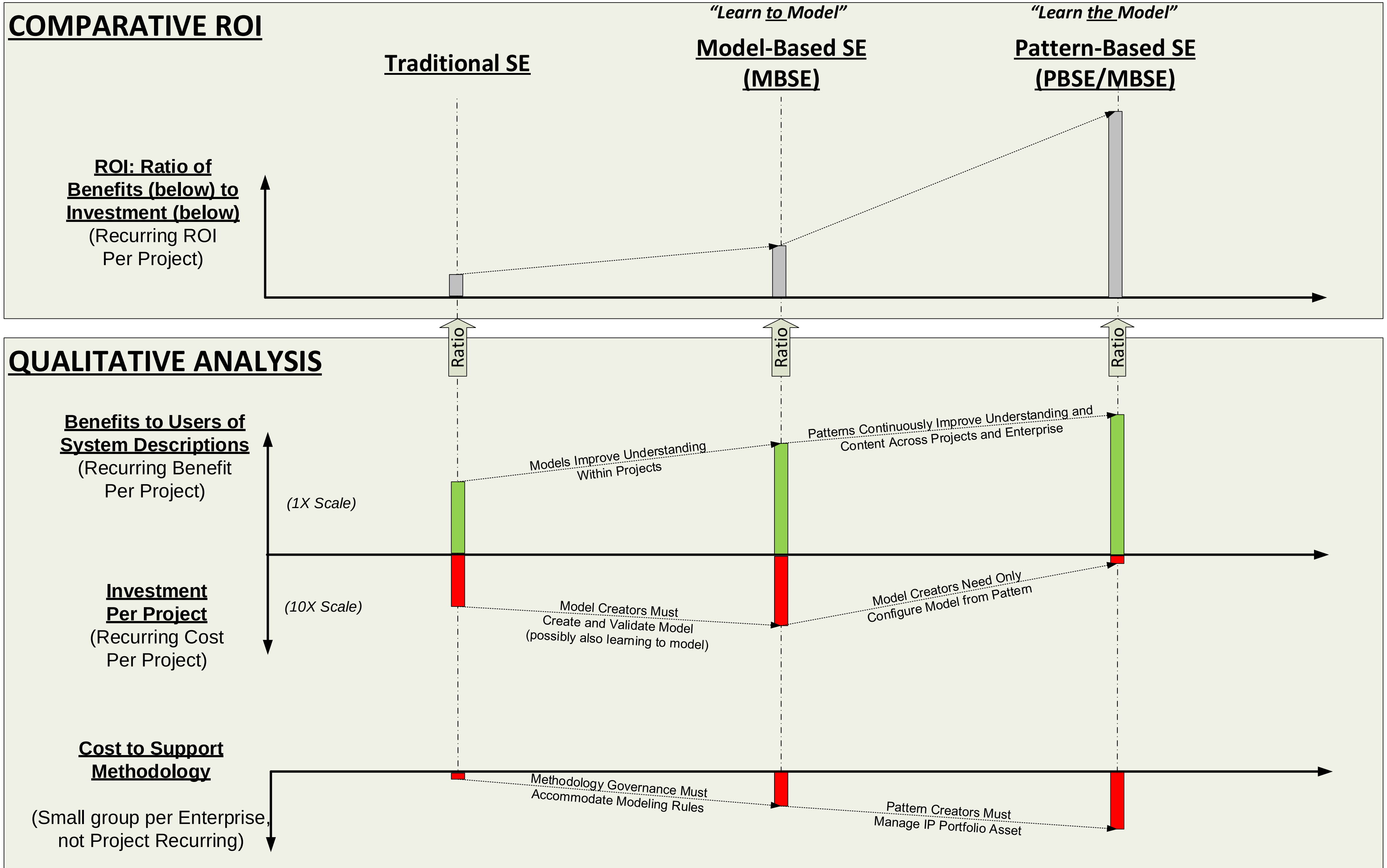
- An S*Model is any model, in any language or tool, that conforms to the S*Metamodel.
- An S*Pattern is a re-usable, configurable S*Model representing a family of systems.
- S*Patterns permit the rapid generation and use of validated MBSE Models, for any of the ISO15288 system life cycle processes.



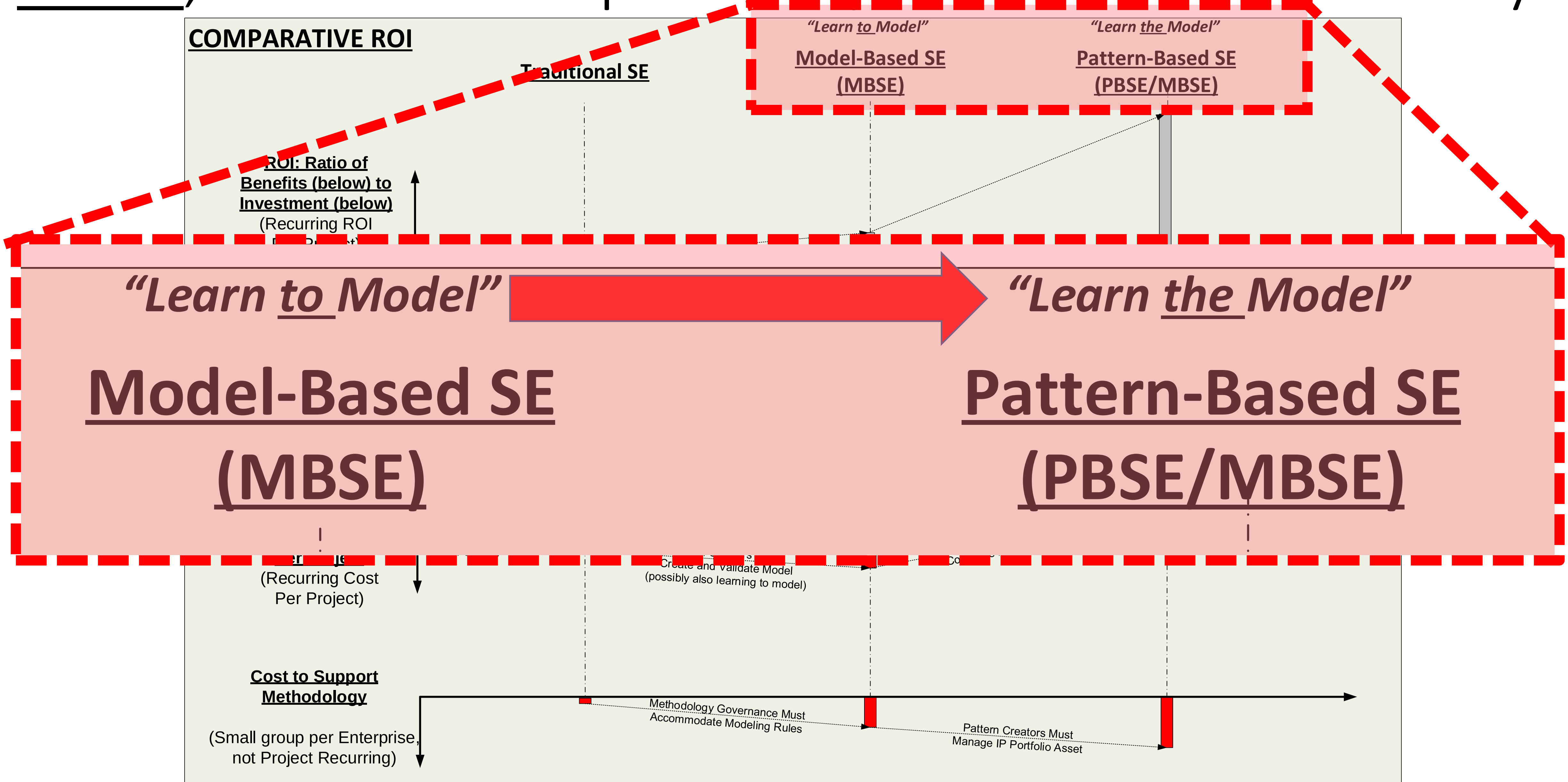
S*Patterns have been created and applied across diverse system domains, over 3 decades:

Medical Devices Patterns	Construction Equipment Patterns	Commercial Vehicle Patterns	Space Tourism Pattern
Manufacturing Process Patterns	Vision System Patterns	Packaging Systems Patterns	Lawnmower Product Line Pattern
Embedded Intelligence Patterns	Systems of Innovation (SOI) Pattern	Consumer Packaged Goods Patterns (Multiple)	Orbital Satellite Pattern
Product Service System Patterns	Product Distribution System Patterns	Plant Operations & Maintenance System Patterns	Oil Filter Pattern
Life Cycle Management System Patterns	Production Material Handling Patterns	Engine Controls Patterns	Military Radio Systems Pattern
Agile Systems Engineering Life Cycle Pattern	Transmission Systems Pattern	Precision Parts Production, Sales, and Engineering Pattern	Higher Education Experiential Pattern

Patterns Improve MBSE Leverage: First in Time and Effort, but More Importantly in Risk and Credibility

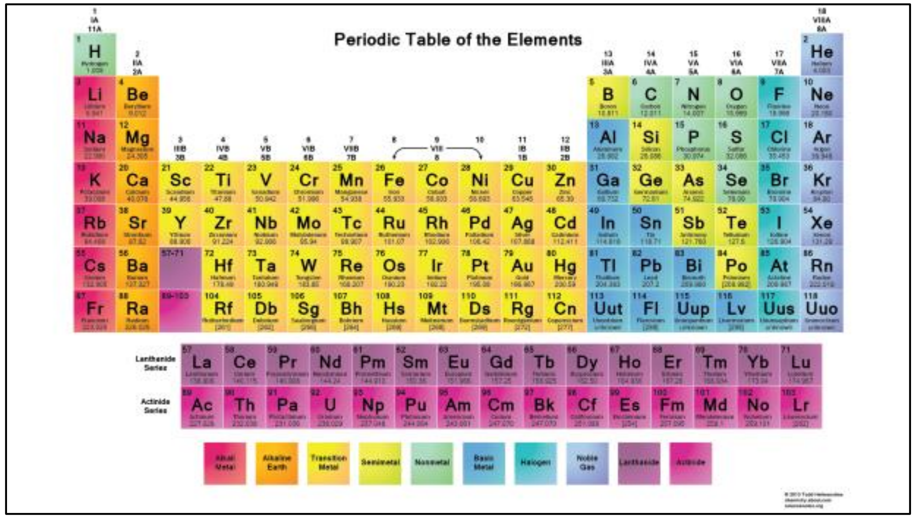


Patterns Improve MBSE Leverage: First in Time and Effort, but More Importantly in Risk and Credibility

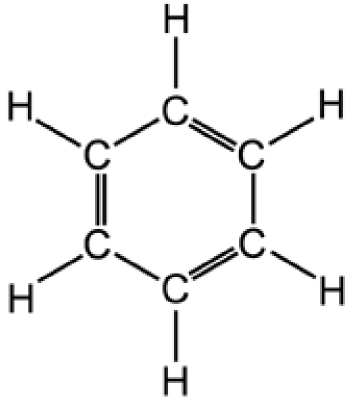


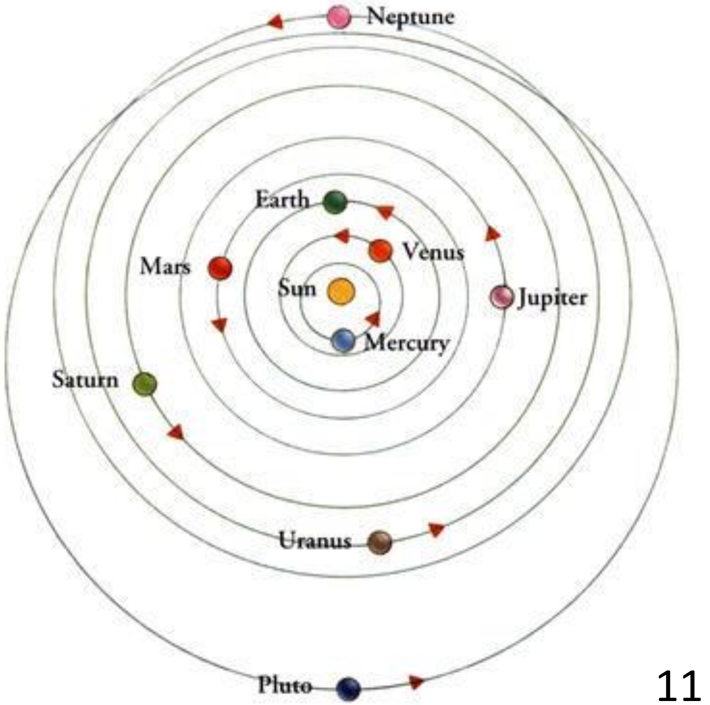
Credibility of Models:
Patterns and the History of Science

Over the last three centuries, the triumph of the physical sciences in lifting human life is based on discovery, community validation, and shared application of recurring, configurable <u>patterns</u> that describe the world's behavior and structure:



$$\nabla \cdot \mathbf{D} = \rho$$
$$\nabla \cdot \mathbf{B} = 0$$
$$\nabla \times \mathbf{E} = -\frac{\partial \mathbf{B}}{\partial t}$$
$$\nabla \times \mathbf{H} = \mathbf{J} + \frac{\partial \mathbf{D}}{\partial t}$$



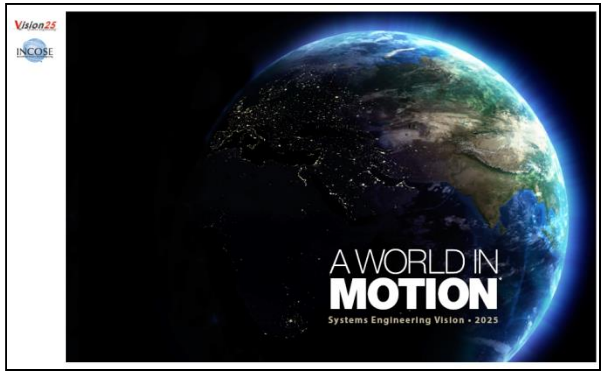


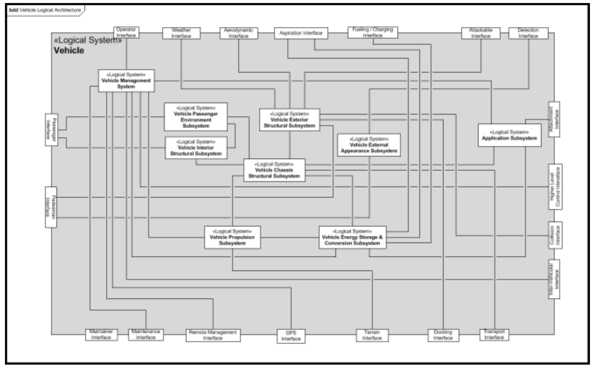
$$H(t)|\psi(t)\rangle = i\hbar\frac{\partial}{\partial t}|\psi(t)\rangle$$

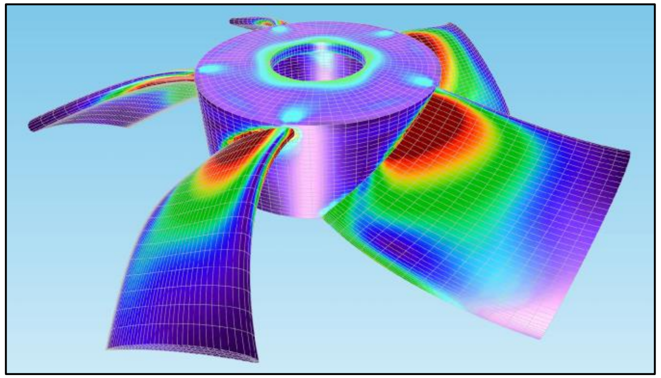
Credibility of Models: Patterns and the History of Science

- Establishing the <u>credibility</u> of models is at the center of the sciences, but . . .
- We observe that in the systems engineering community, “how to create models” seems to get more attention than “how to perform model verification, validation, and uncertainty quantification (VVUQ)”
- Efforts of recent years, such as the ASME Model VVUQ Standards activity, illustrate that the cost of model-based “virtual system verification” includes establishing model VVUQ—thereby raising the bar and the cost of models.

Enthusiasm for Models





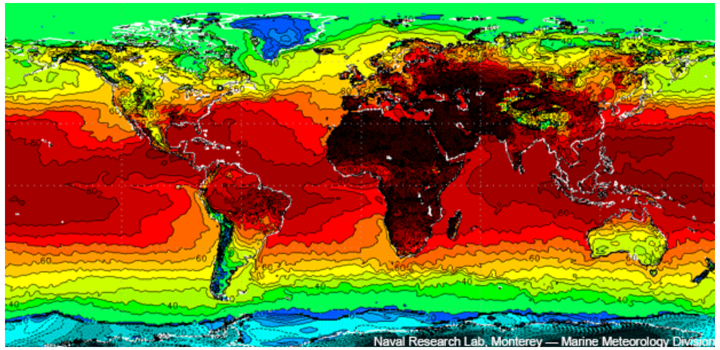


The INCOSE systems community has shown growing enthusiasm for "engineering with models" of all sorts:

- Historical tradition of math-physics engineering models
- A World in Motion: INCOSE Vision 2025
- Growth of the INCOSE IW MBSE Workshop
- Growth in systems engineers in modeling classes
- INCOSE Board of Directors' objective to accelerate transformation of SE to a model-based discipline
- Joint INCOSE activities with NAFEMS

If we expect to use models to support critical decisions, then we are placing *increased trust in models*:

- Critical financial, other business decisions
- Human life safety
- Societal impacts
- Extending human capability



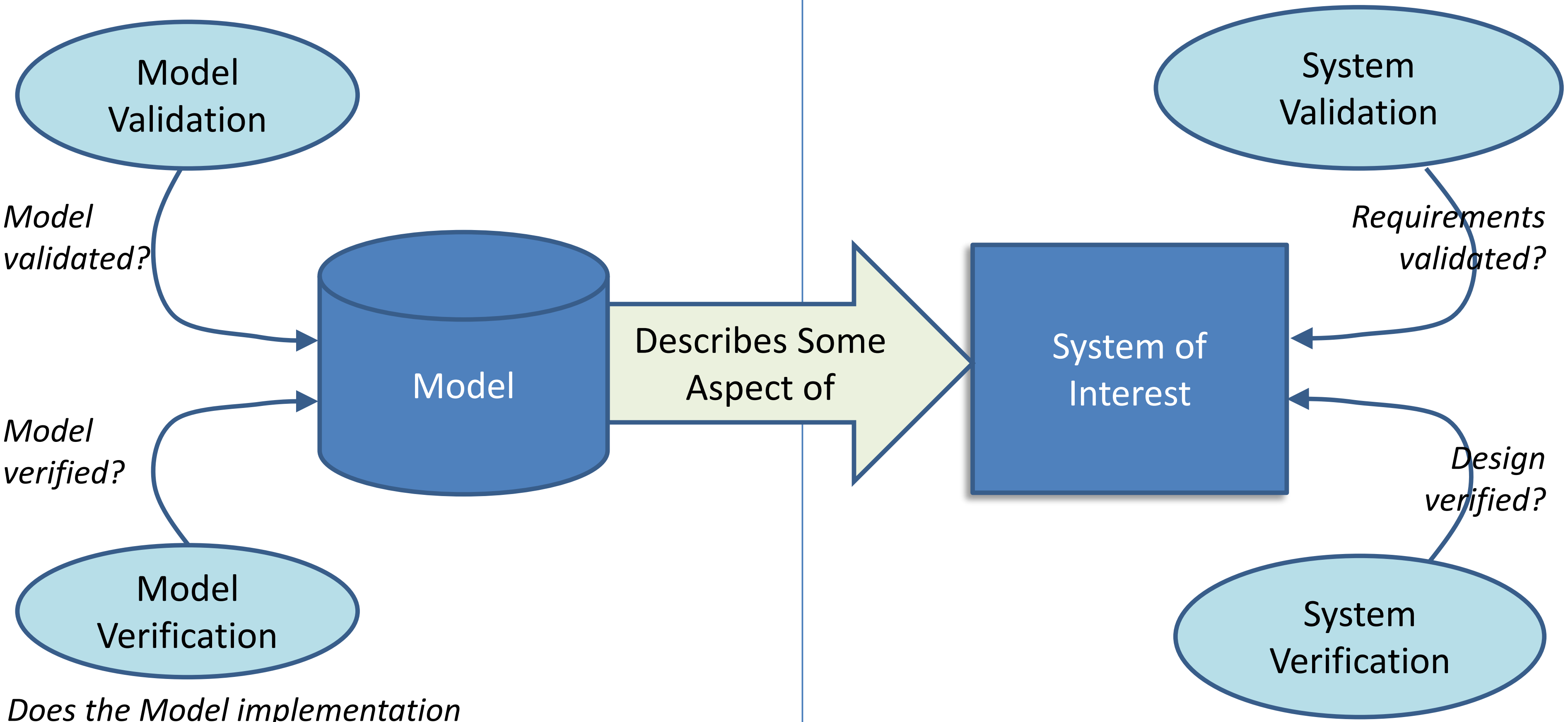
- MBSE Maturity requires that we characterize the structure of that trust and manage it:
    - The Validation, Verification, and Uncertainty Quantification (VVUQ) *of the models themselves*.

V&V of *Models*, Per Emerging ASME Model V&V Standards

Does the Model adequately describe what it is intended to describe?

V&V of *Systems*, Per ISO 15288 & INCOSE Handbook

Do the System Requirements describe what stakeholders need?

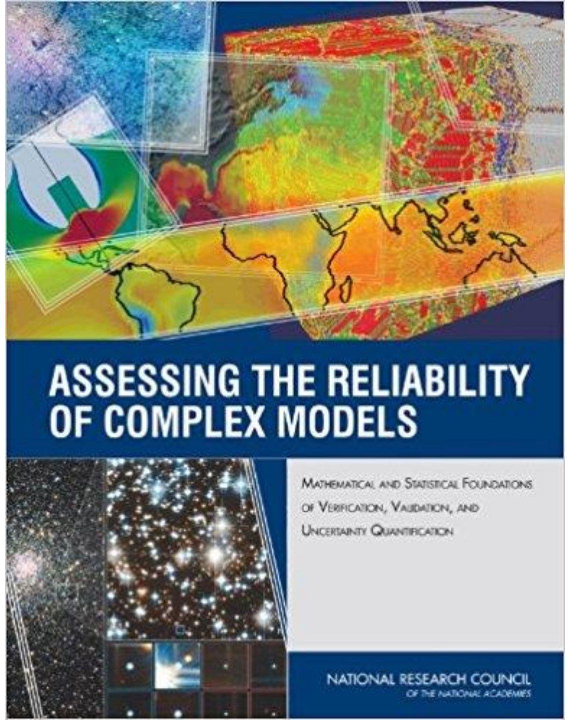


Does the Model implementation adequately represent what the Model says?

Does the System Design define a solution meeting the System Requirements?

Don't forget: A model (on the left) <u>may</u> be used for system verification or validation (on the right!)

Quantitative Credibility, including Uncertainty Quantification (UQ)

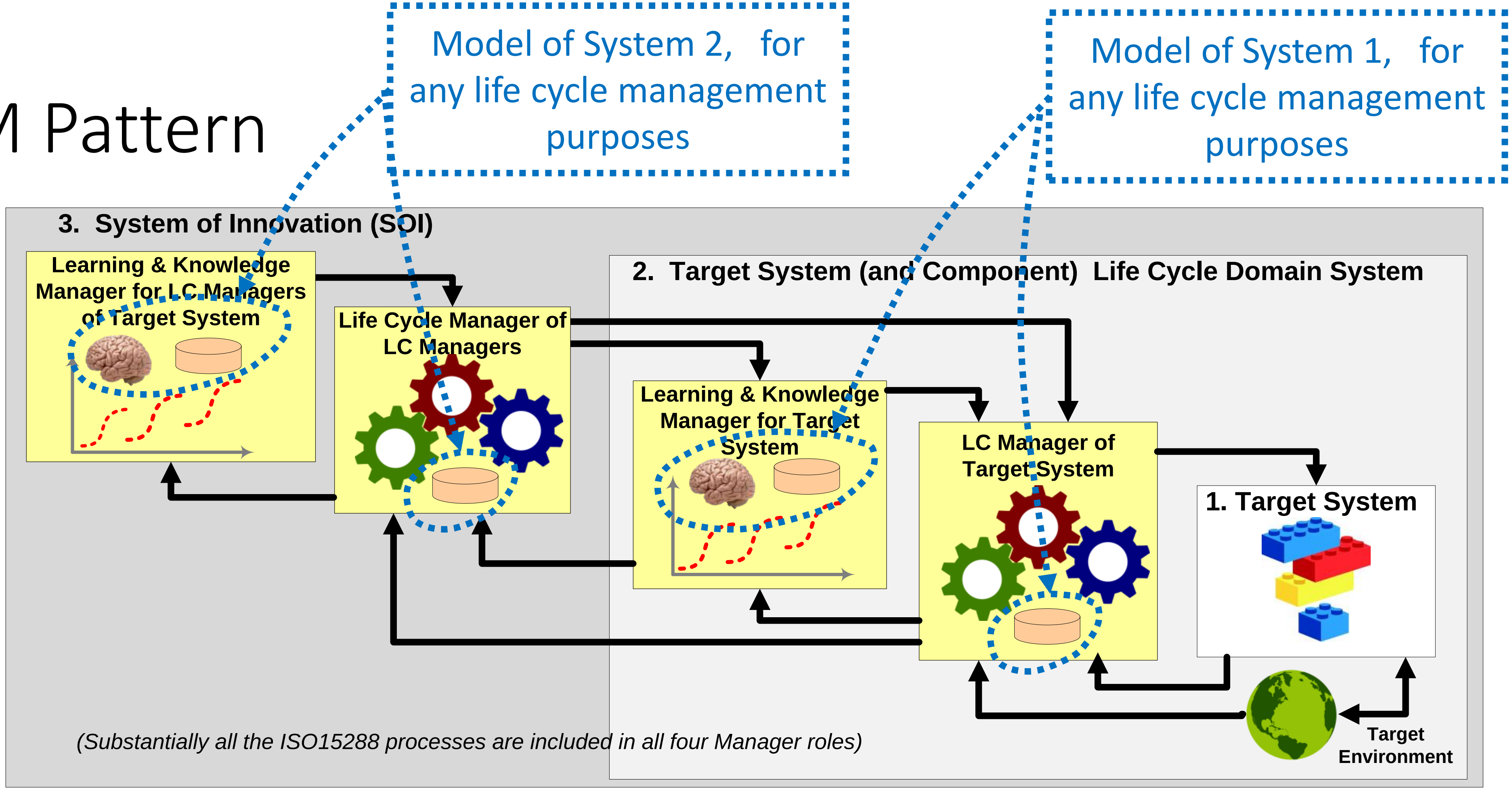


- There is a body of literature on a mathematical subset of the UQ problem, in ways viewed as the heart of this work.
- But, some additional systems work is needed, and in progress, as to the more general VVUQ framework, suitable for general standards or guidelines.

General structure of uncertainty / confidence tracing:

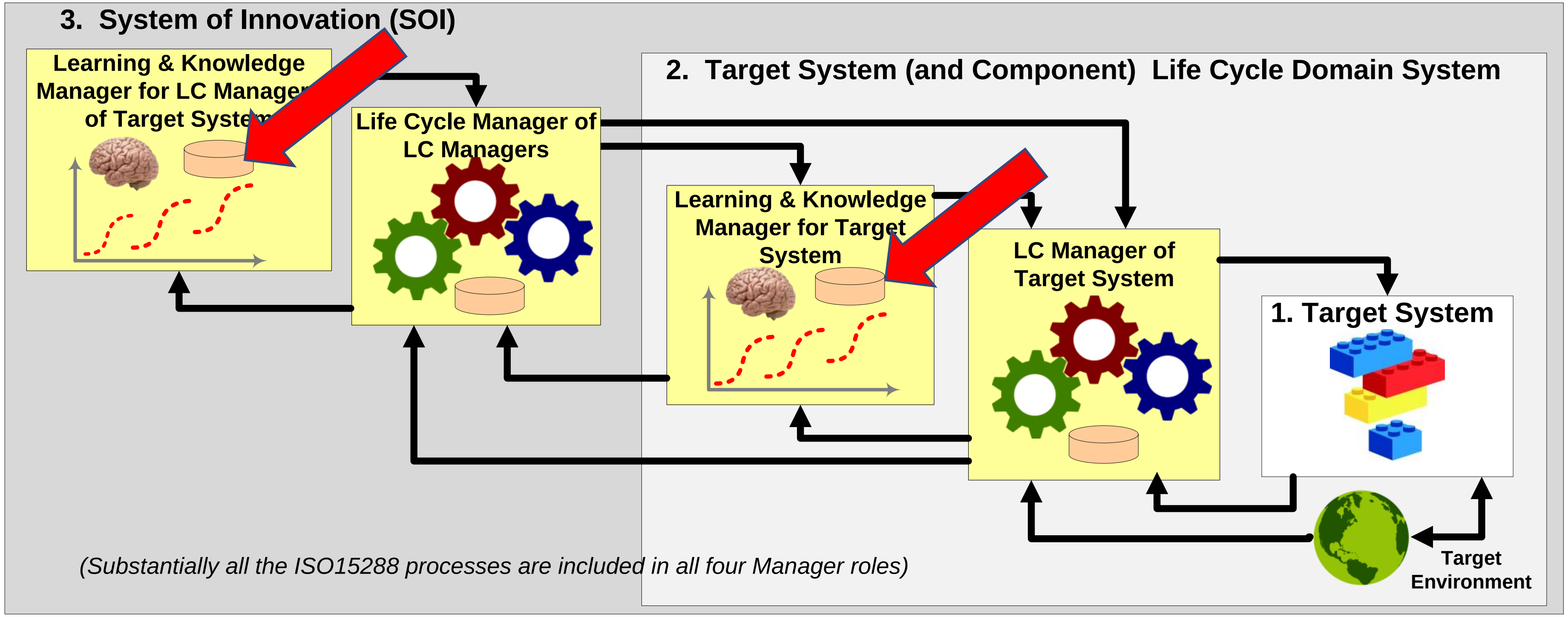
- Do the modeled external Interactions qualitatively cover the modeled Stakeholder Features over the range of intended situations of interest?
- Quantify confidence / uncertainty that the modeled Stakeholder Feature Attributes quantitatively represent the real system concerns of the Stakeholders with sufficient accuracy over the range of intended situation envelopes.
- Quantify confidence / uncertainty that the modeled Technical Performance Attributes quantitatively represent the real system external behavior of the system with sufficient accuracy over the range of intended situation envelopes.

INCOSE ASELCM Pattern



- System 1: Target system of interest, to be engineered or improved.
- System 2: The environment of (interacting with) S1, including all the life cycle management systems of S1, including learning about S1.
- System 3: The life cycle management systems for S2, including learning about S2.

An emerging special case: Regulated markets



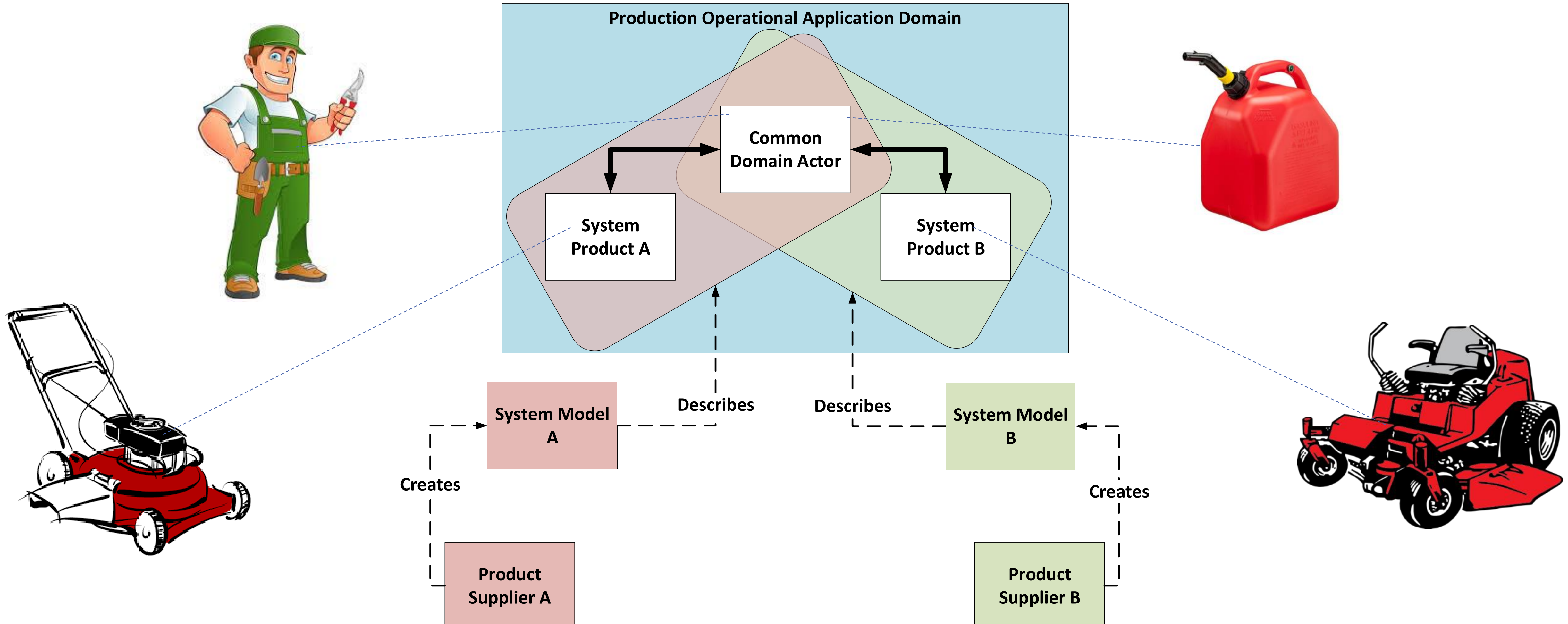
- Trusted shared MBSE Patterns for classes of systems
- Configurable for vendor-specific products
- With Model VVUQ frameworks lowering the cost of model trust for regulatory submissions

An emerging special case: Regulated markets

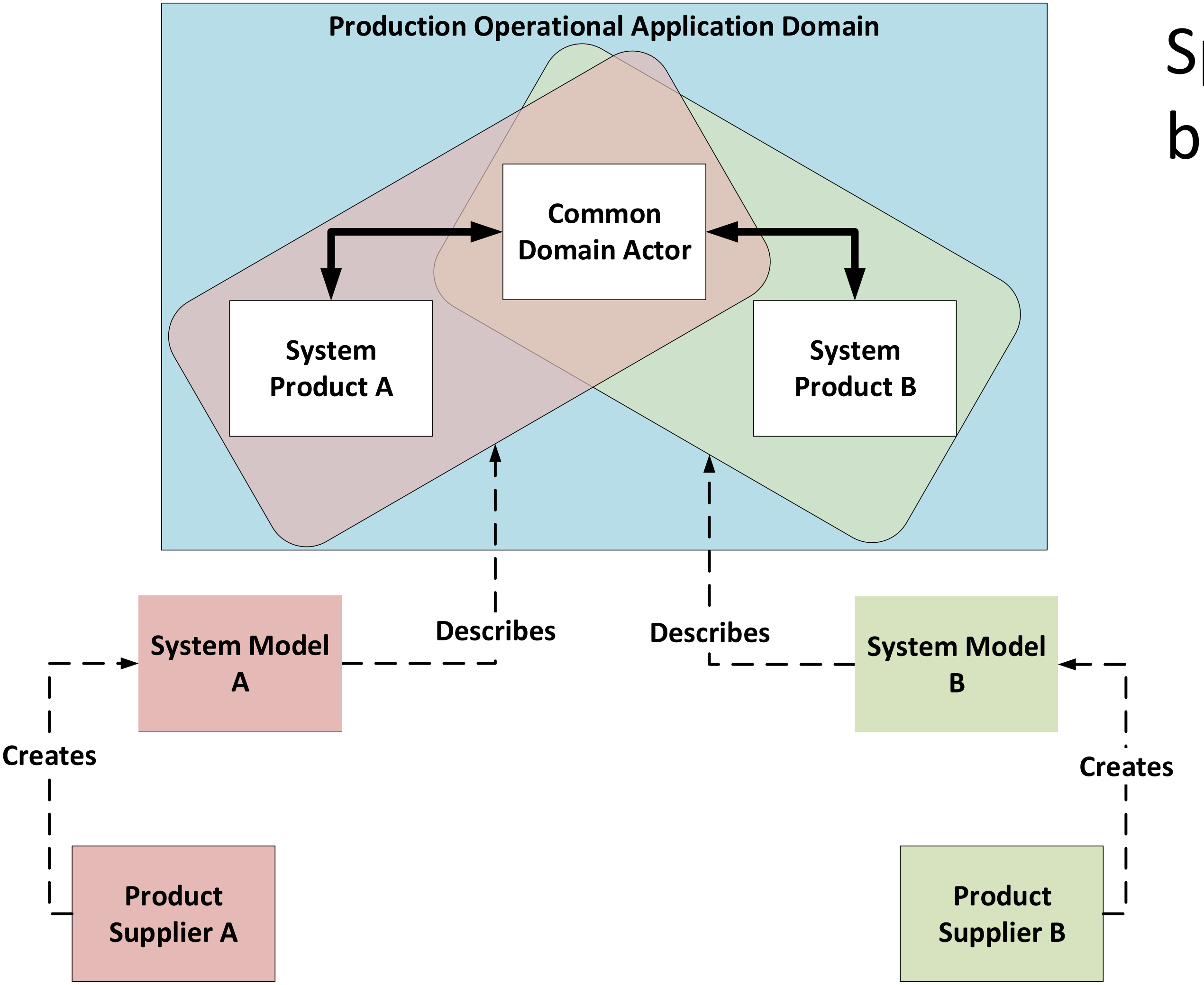
- Increasing use of computational models in safety-critical, other regulated markets is driving development of methodology for Model VVUQ:
  - See, for example, ASME V&V 10, 20, 30, 40, 50, 60.
- Models have economic advantages, but the above can add new costs to development of models for regulatory submission of credible evidence:
  - Cost of evidentiary submissions to FDA, FAA, NRC, NTSB, EPA, OSHA, when supported by models—includes VVUQ of those models.
- This suggests a vision of collaborative roles for engineering professional societies, along with regulators, and enterprises:
  - Trusted shared MBSE Patterns for classes of systems
  - Configurable for vendor-specific products
  - With Model VVUQ frameworks lowering the cost of model trust for regulatory submissions
- Further emphasizes the issue of trust in models . . .

Protecting and Sharing IP in S*Pattern Families

Consider an <u>innovative</u>, <u>competitive</u>, and possibly <u>regulated</u>, market, where competitive product suppliers A and B create model-described products:



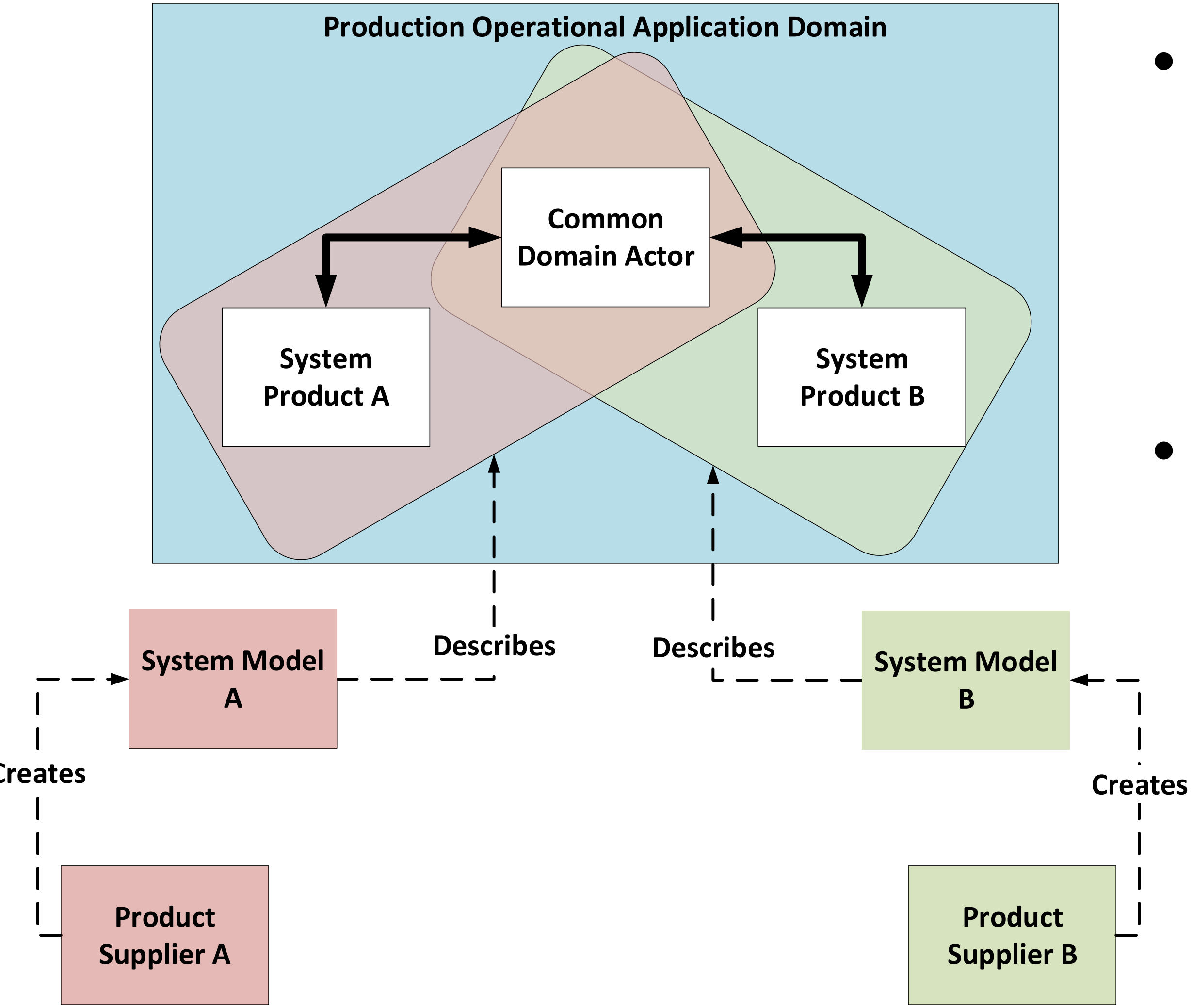
Protecting and Sharing IP in S*Pattern Families



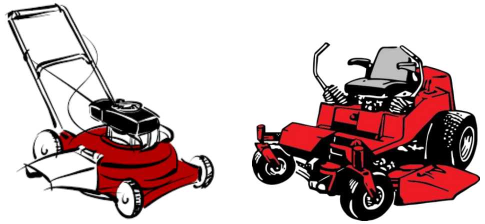
Speed and effectiveness of innovation may be enhanced by <u>sharing</u>; e.g.:

- Descriptions of <u>interfaces</u> that appear on competitive systems but must interact with each other or with other common actors
- Descriptions of regulatory expectations as to <u>safety</u>, and <u>evidence</u> of its achievement
- Guidelines or standards as to <u>credibility of model-based descriptions of the above</u>

Protecting and Sharing IP in S*Pattern Families

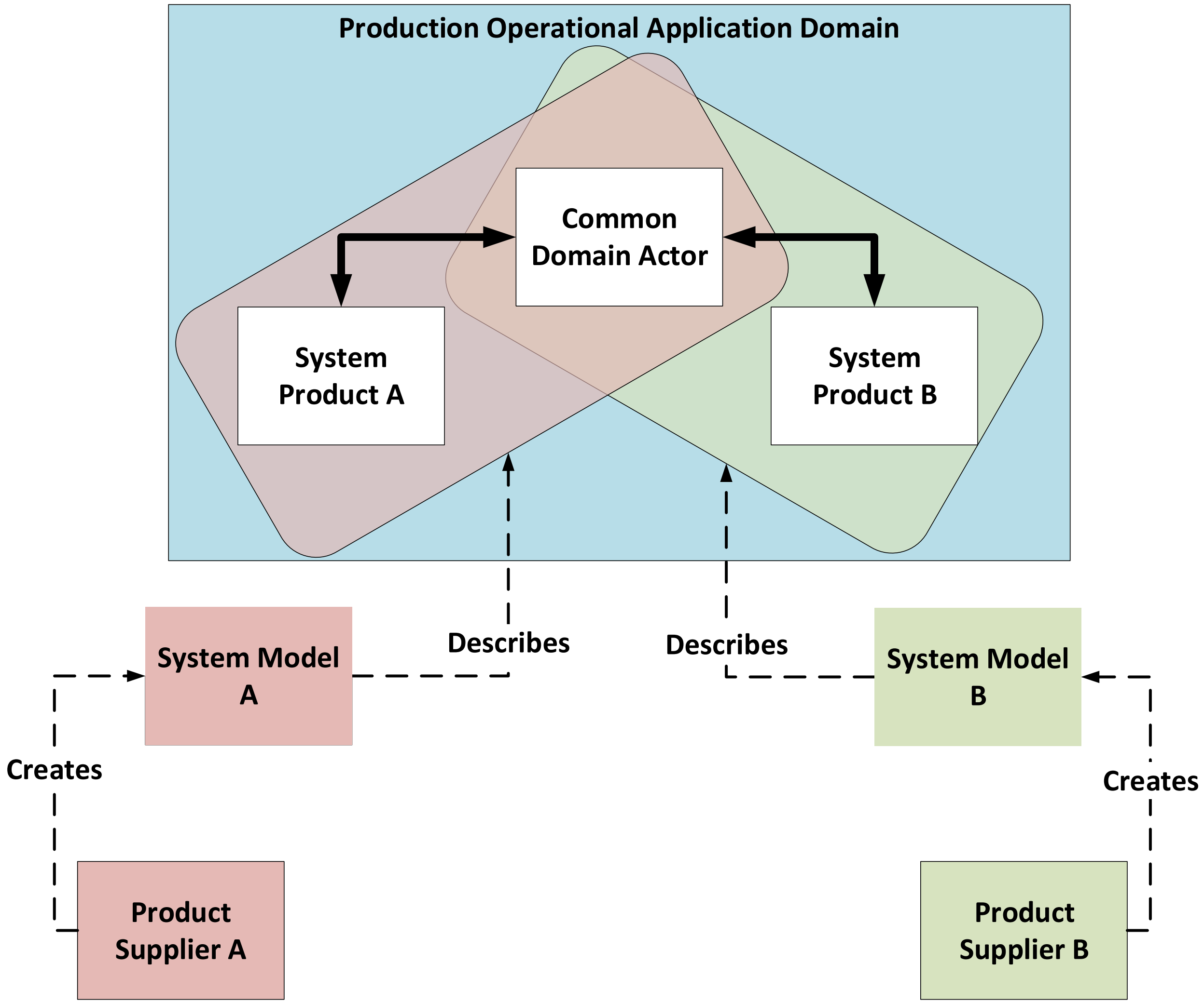


- But some aspects of the competitive systems will involve market-differentiating proprietary IP, that the competitors want to keep confidential.



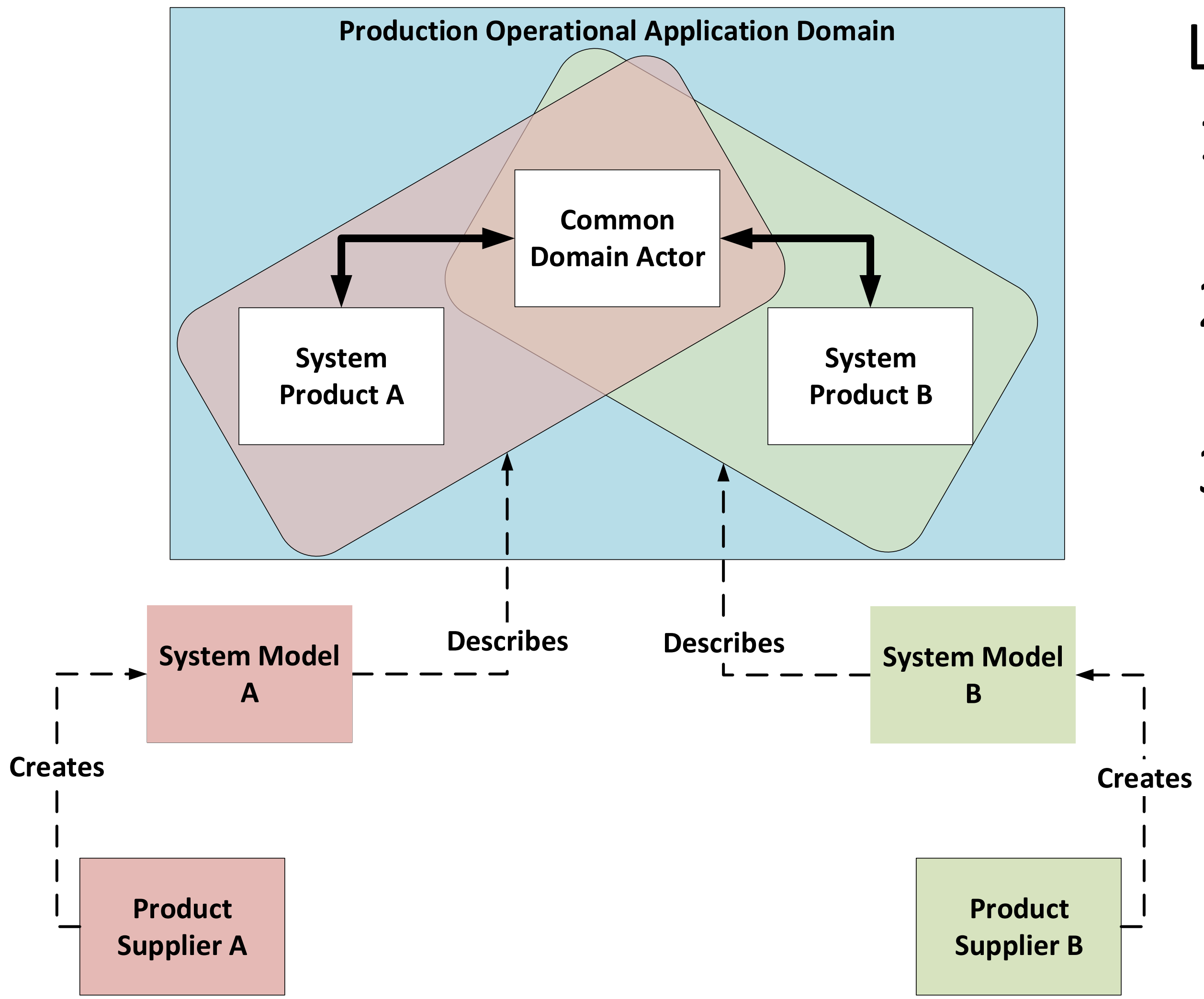
- So, how do we:
  1. Share some content, while . . .
  2. Keeping other content confidential, but . . .
  3. Making sure the <u>integrated</u> system described works as expected (that is, the two partitions of data are not in conflict)?

Protecting and Sharing IP in S*Pattern Families



- The work load on the regulatory process, and ability of regulators and businesses to avoid getting bogged down, depend on whether submissions arrive looking very unique, versus very related.
- Can the regulator and submitter establish common expectations about overall regulated parameters and credibility of related evidence?

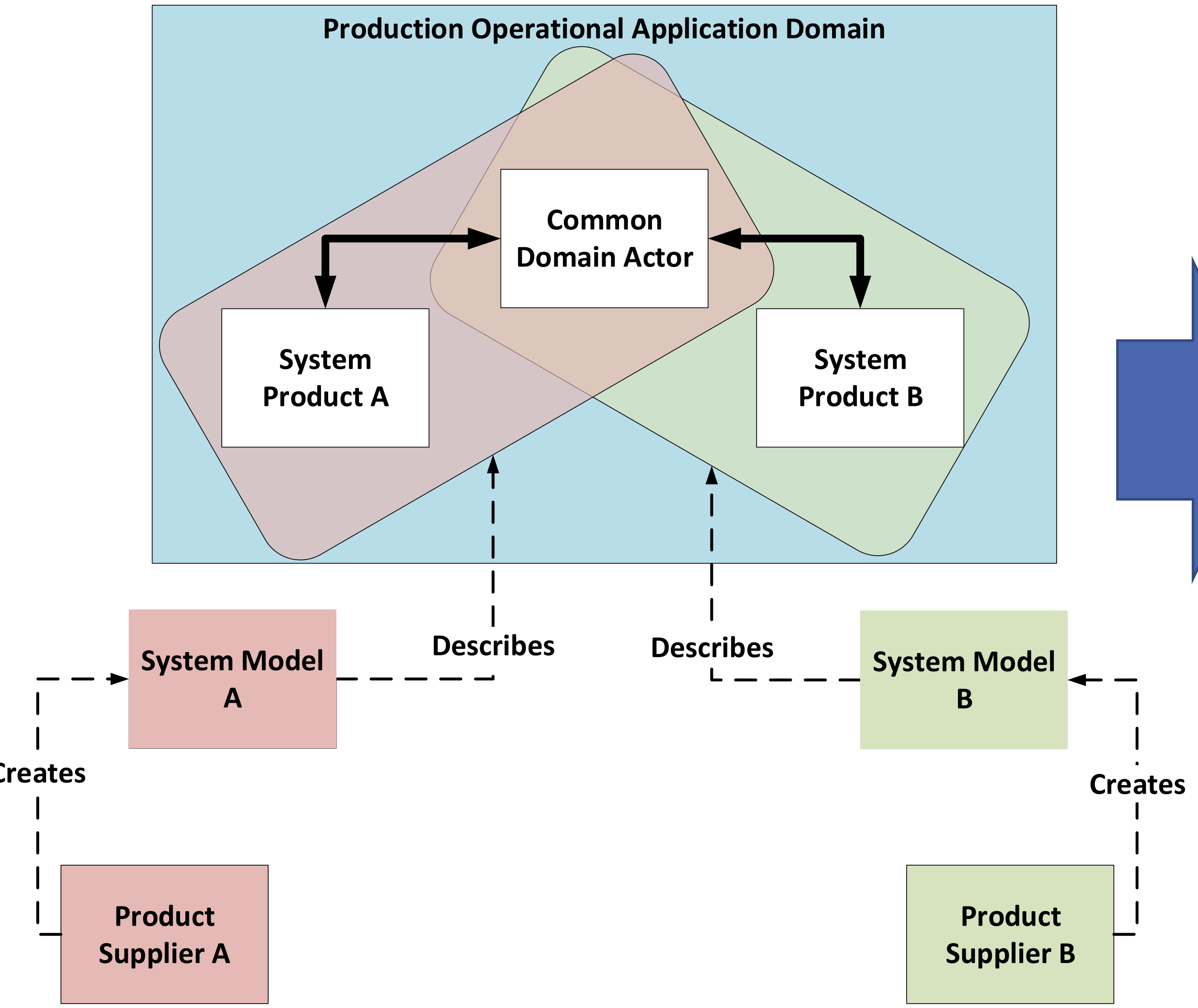
Protecting and Sharing IP in S*Pattern Families

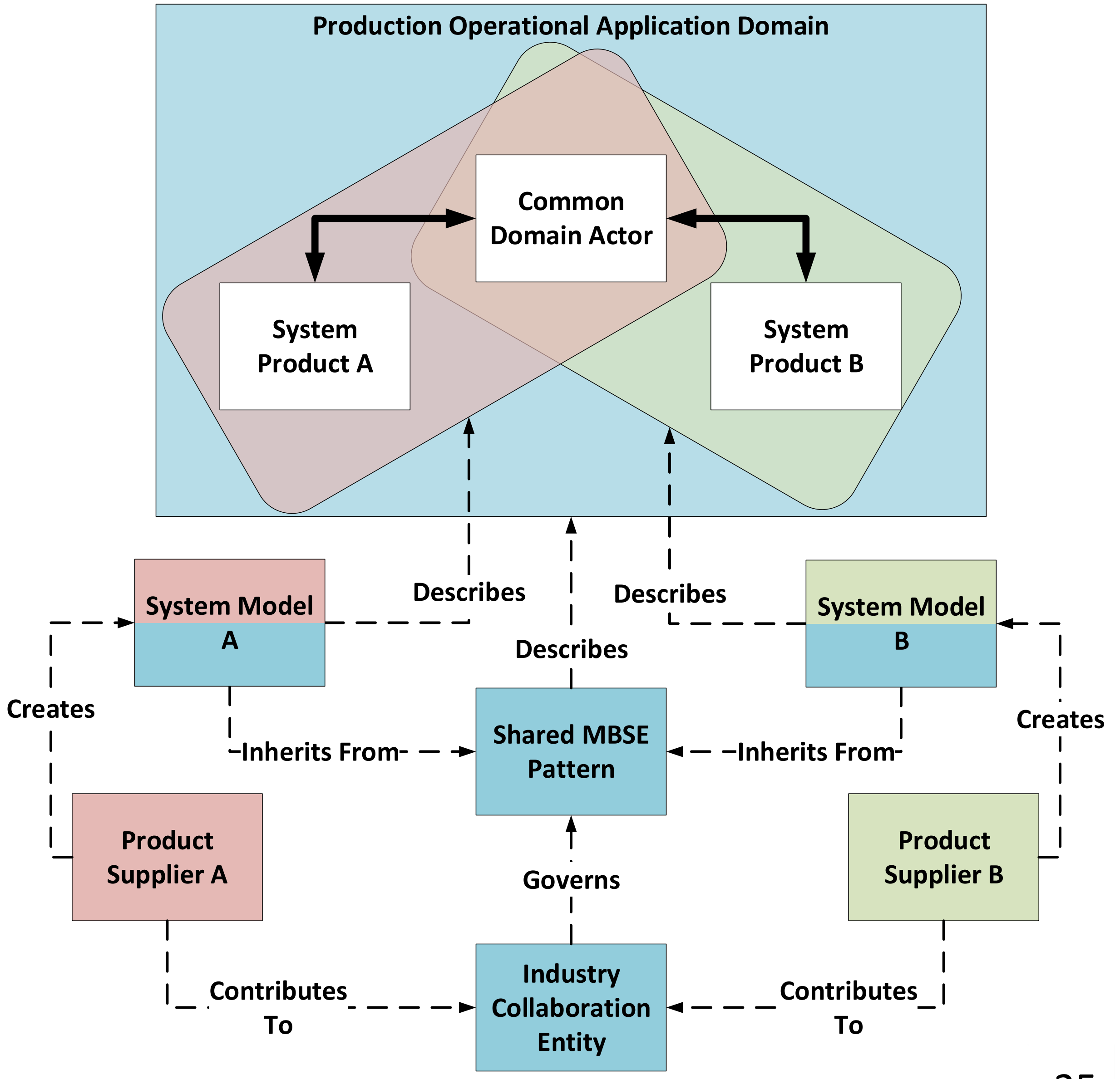


Larger questions: How do we--

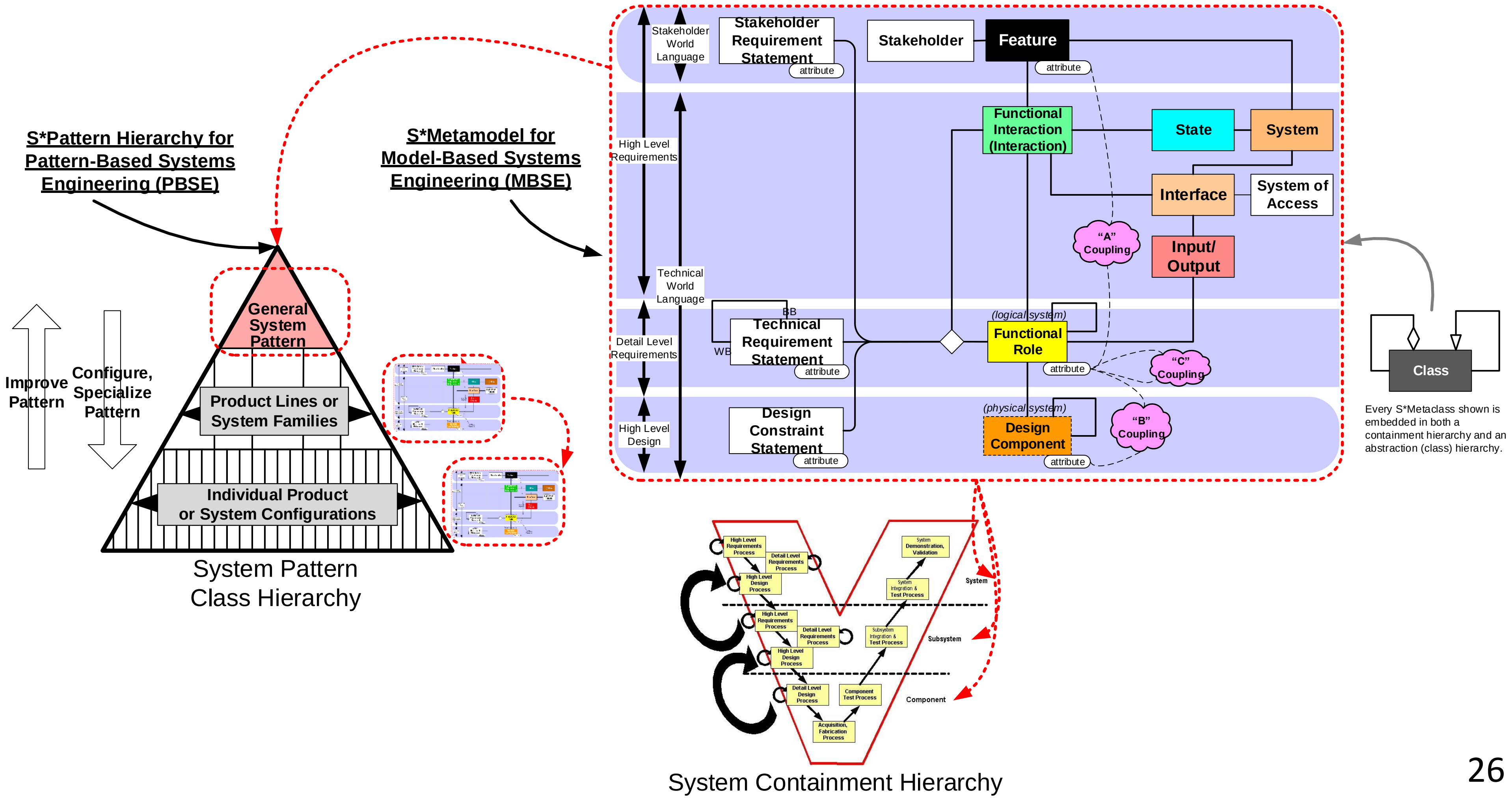
1. Create innovative market differentiating content, while . . .
2. Describing it in a regulatory context of what is still fixed, and . . .
3. Create sufficient confidence in related models (at low enough model VVUQ cost) to trust them for evidence of that performance?

Answer: Hybrid Patterns in the Public Square

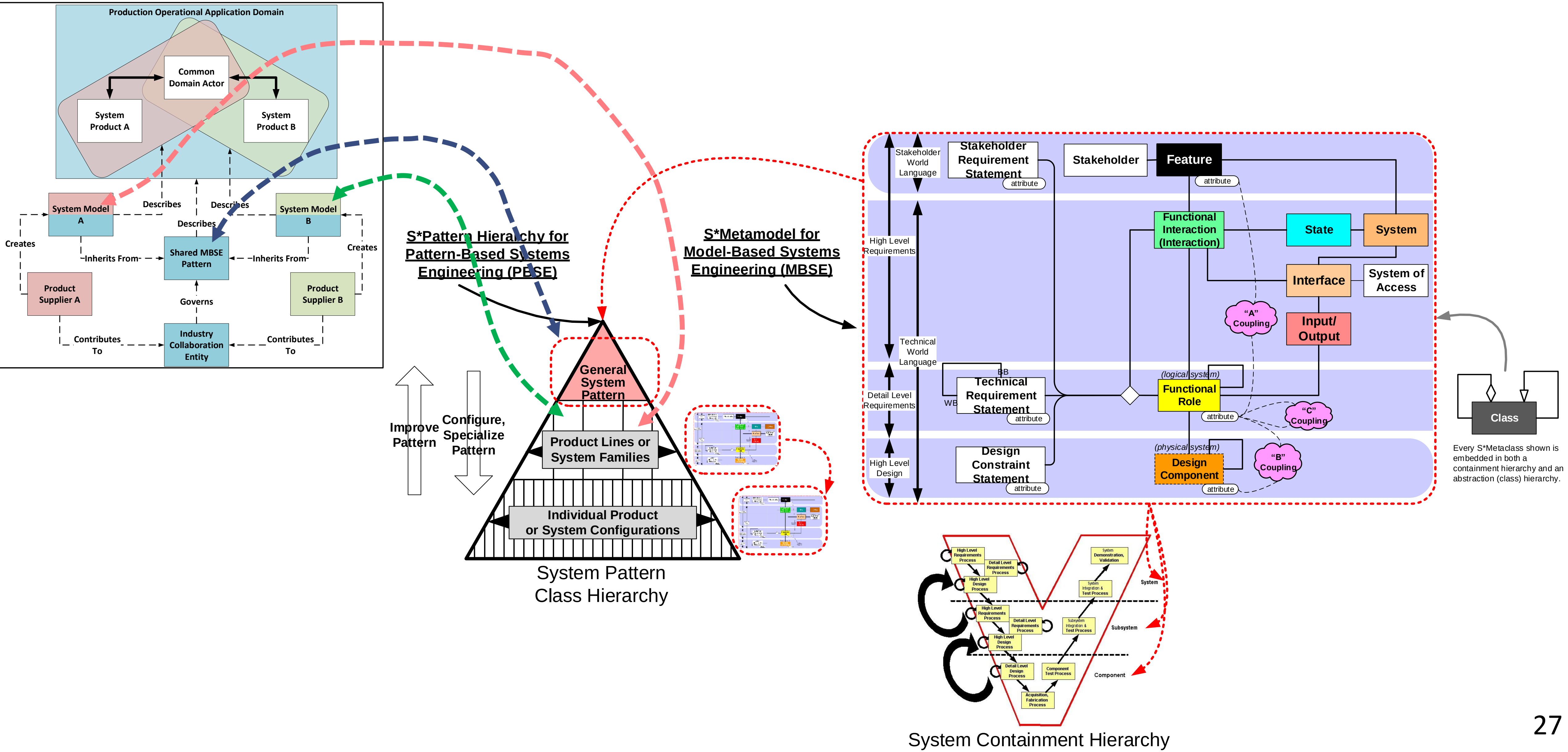




Protected IP, Coordinated with Shared Public IP



Protected IP, Coordinated with Shared Public IP



Examples of Public Square Shared Model Activity

- Consortium-generated technical standards, frameworks: Not new.
- But, expressing them as <u>system models</u> emerging more recently.
- Examples of related efforts:
  - Trustable models: ASME Model VVUQ Standards activity
  - Domain specific example: EPRI CIM Electrical Power Industry Model
  - Harvesting patterns from legacy descriptions
  - V4 Institute: expanding capabilities in virtual verification
  - Model-Based Standards Authoring (MBSA)

Trustable models: ASME Model VVUQ Standards activity

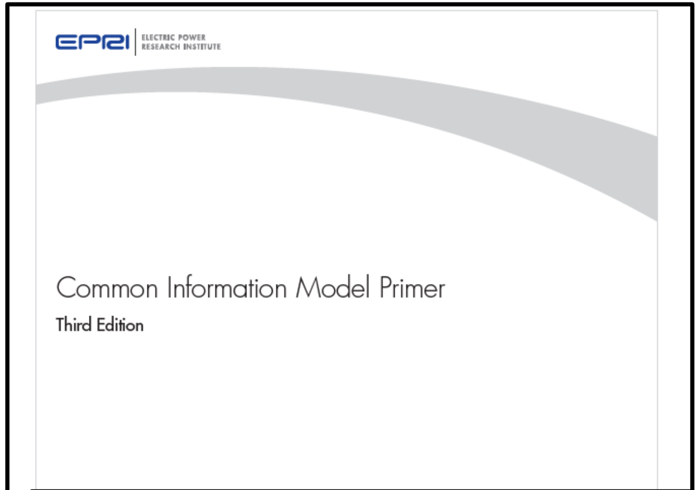
- ASME has an active set of industry teams writing guidelines and standards on the Verification and Validation of Computational Models:
  - Inspired by the proliferation of computational models (FEA, CFD, Thermal, Stress/Strain, etc.)
  - Includes regulator participants (FDA, FAA)
  - It could fairly be said that this historical background means that effort was not focused on what most systems engineers would call “system models”
- ASME also conducts annual Symposium on Validation and Verification of Computational Models, in May.
- To participate in this work, in 2016 the speaker joined the ASME VV50 Committee:
  - With the idea that the framework ASME set as foundation could apply well to systems level models; and . . .
  - with a pre-existing belief that system level models are not as different from discipline-specific physics models as believed by systems community.

Trustable models: ASME Model VVUQ Standards activity

- V&V 10: Verification & Validation in Computational Solid Dynamics
- V&V20: Verification & Validation in Computational Fluid Dynamics and Heat Transfer
- V&V 30: Verification and Validation in Computational Simulation of Nuclear System Thermal Fluids Behavior
- V&V 40: Verification and Validation in Computational Modeling of Medical Devices
- V&V 50: Verification & Validation of Computational Modeling for Advanced Manufacturing
- V&V 60: Verification and Validation in Modeling and Simulation in Energy Systems and Applications

Domain specific example: EPRI CIM Electrical Power Industry Model

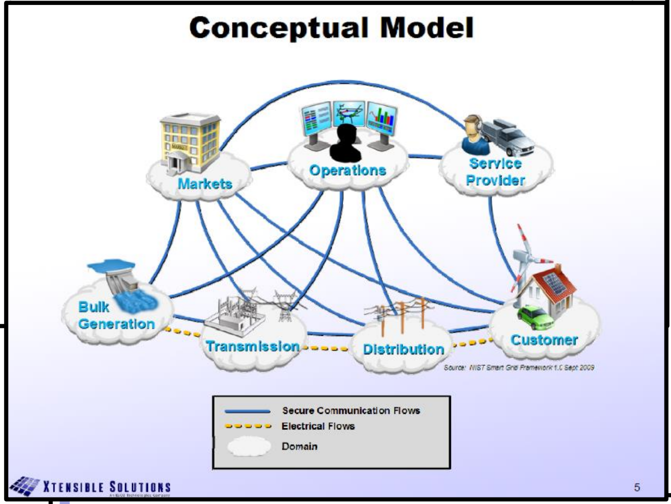
- Industry-defined configurable model of electrical utility network, related systems, originated in 1990’s, substantial subsequent growth and applications added.
- Neutral model-based core (in UML), diverse applications across network planning and engineering, operations and restoral, sales and commercial aspects, across generation, transmission, distribution, and customer premises.
- Originated by industry consortium (EPRI), now basis of several global IEC standards:
    - IEC 61970 (network model, equipment profile, schematics, analog measurement profile, discrete measurement profile, state variable profile, SCADA, energy, XML file exchange) WG 13
    - IEC 61968 (assets, metering, GIS, messaging) WG 14
    - IEC 62325 (energy markets) WG 16

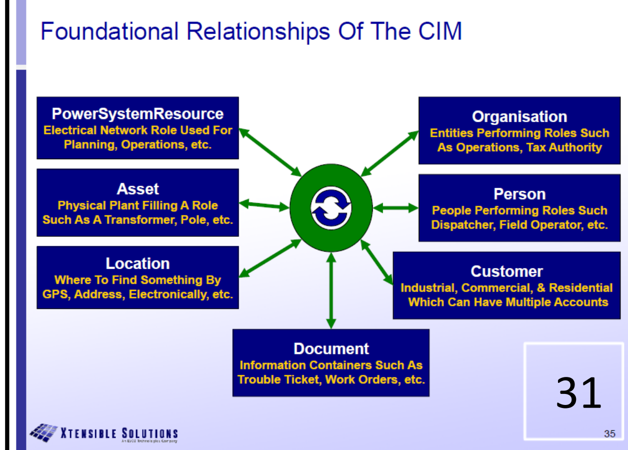


EPRI | ELECTRIC POWER RESEARCH INSTITUTE

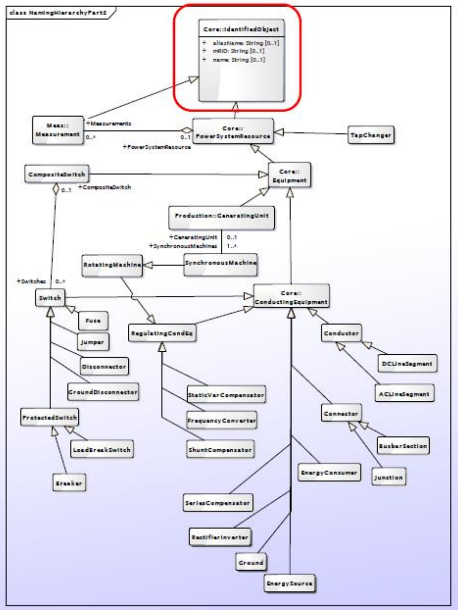
Common Information Model Primer

Third Edition





Naming and Equipment Hierarchy Part 2



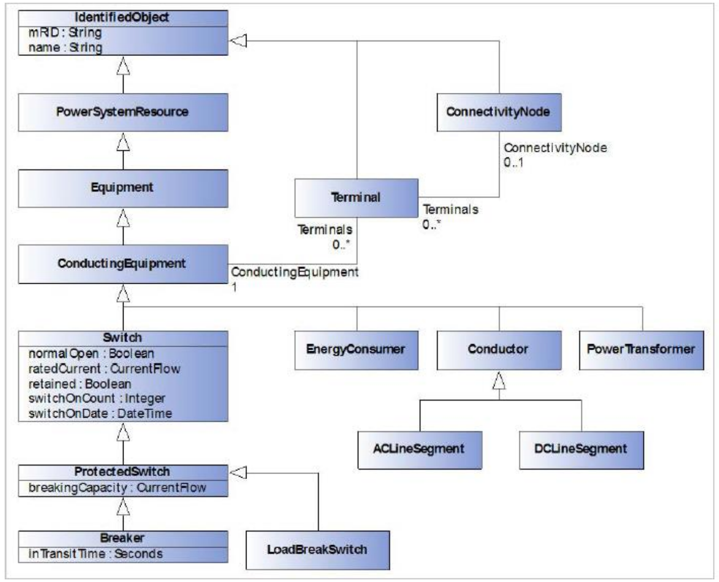
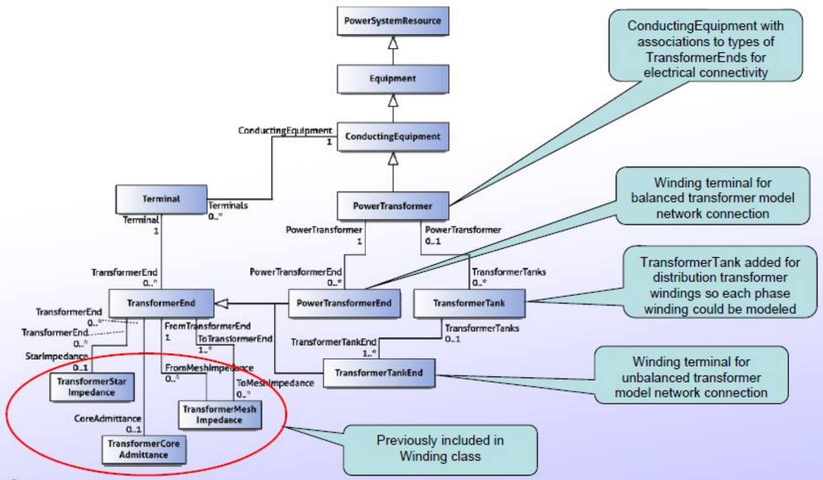


Figure 5-8
Conducting Equipment and Connectivity class diagram

Transformer Class Diagram CIM Release 15



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The *GeneratingUnit* class does not represent a piece of conducting equipment that physically connects to the network; instead it represents "a single or set of synchronous machines for converting mechanical power into alternating-current" as defined in the CIM.

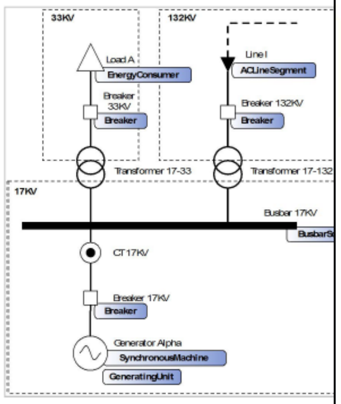


Figure 5-12
Example Circuit with Partial CIM Class Mappings

These mappings are shown in Figure 5-12, leaving only the two power transformers and current transformer to be mapped to CIM classes.

Transformers Prior to CIM v15

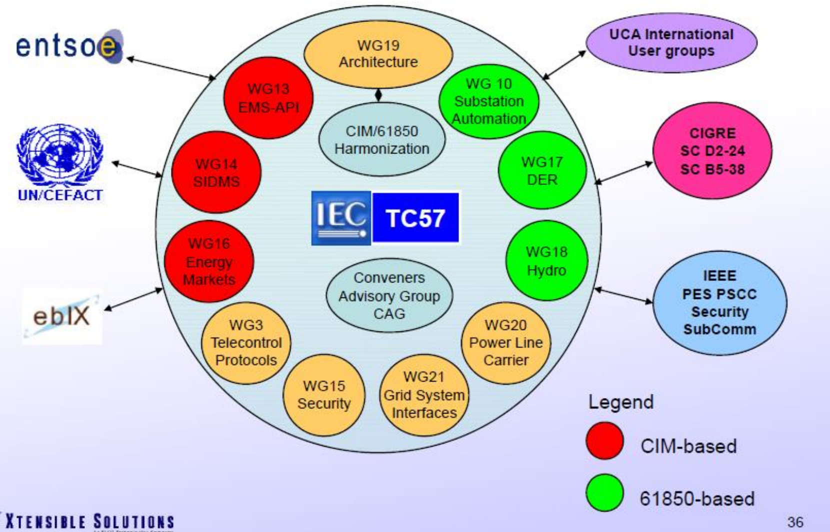
Prior to 2011 the CIM Transformer Model had been relatively unchang… its inception. The model reflected the typical EMS representation of a … transformer which is not mapped to a single CIM class; instead it is spli… into a number of components with a single *PowerTransformer* class. A … terminal power transformer becomes two *TransformerWinding* objects w… *PowerTransformer* container. If a tap changer is present to control one o…

◂ 5-12 ▸

CIM UML in Enterprise Architect

- The CIM UML model is maintained in Sparx Enterpris… Architect (EA)
- Current Official CIM Releases of UML Model
  - iec61970cim16v29a_iec61968cim12v08_iec62325cim03v01… (official release 16 WG13)
  - iec61970cim17v04_iec61968cim12v09_iec62325cim03v01a (updated by WG14)
  - iec61970cim17v07_iec61968cim12v10_iec62325cim03v02 (current model release)
- Go to UML model in EA

Who Manages the CIM UML Model?
- TC 57 Organization and Formal Liaisons



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12: Free and Open Source Tools

MODSARUS®: MODelling SmartGrid ARchitecture Unified Solution

MODSARUS has been developed as an add-in of Enterprise Architect (EA) software from Sparx Systems, already chosen by IEC TC57 for developing the Common Information Model (CIM)-related standards. MODSARUS is leveraging the standardized modeling approach as well as a Model Driven Architecture approach in an integrated UML platform in order to facilitate the development of Smart Grid data exchanges from any reference data models. The core idea of the approach is to produce an automatic implementation code from UML models designed by architects employing graphic user interfaces to guide humans and shadow modeling rules complexity.

CIMTool

CIMTool is a commonly encountered tool for creating profiles (a collection of classes that fully describe the information to be modeled or exchanged) from the larger enterprise semantic model, in this case the IEC CIM. CIMTool is open source, meaning a copy can be obtained at no charge from the CIMTool Download Page. It is implemented as a plug-in for the Eclipse platform. CIMTool is most commonly used for creating new profiles, editing those created in EA, and checking for inconsistencies. The tool can also validate messages against profiles.

CIM EA

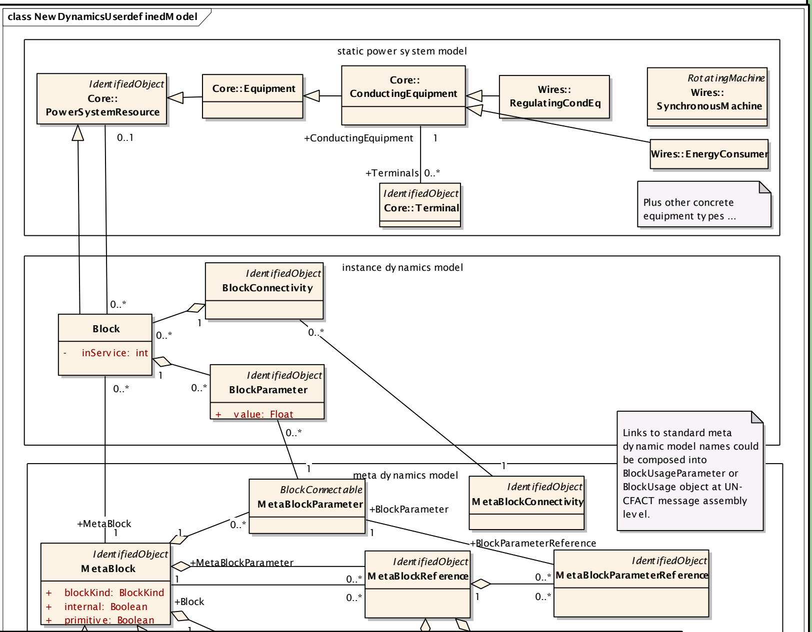
CIM EA is a free, but not open source add-in to EA. CIM EA extends EA to provide an environment in which developers can manage the IEC CIM, CIM Profiles, and CIM-based artifacts.

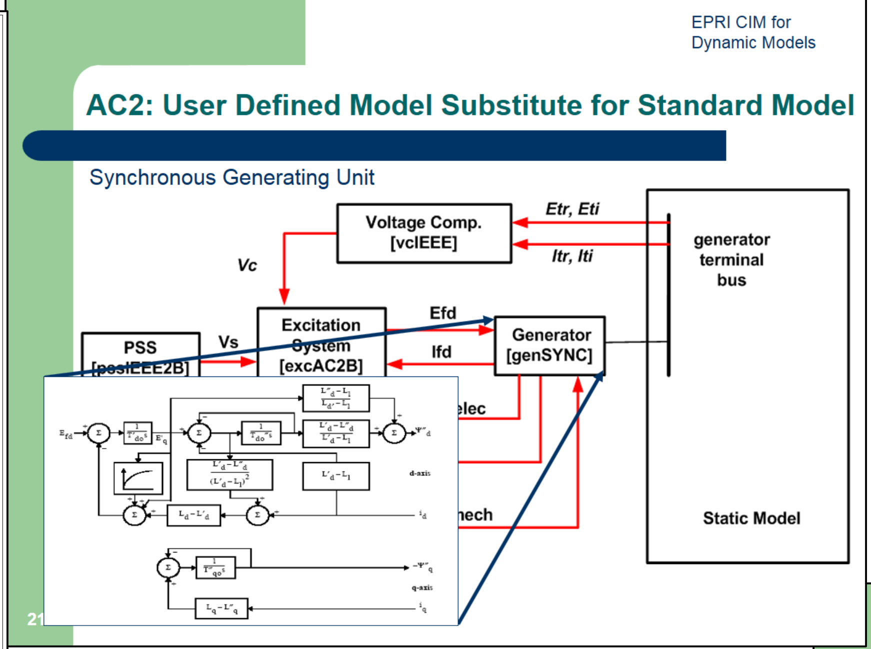
http://www.cimea.org/

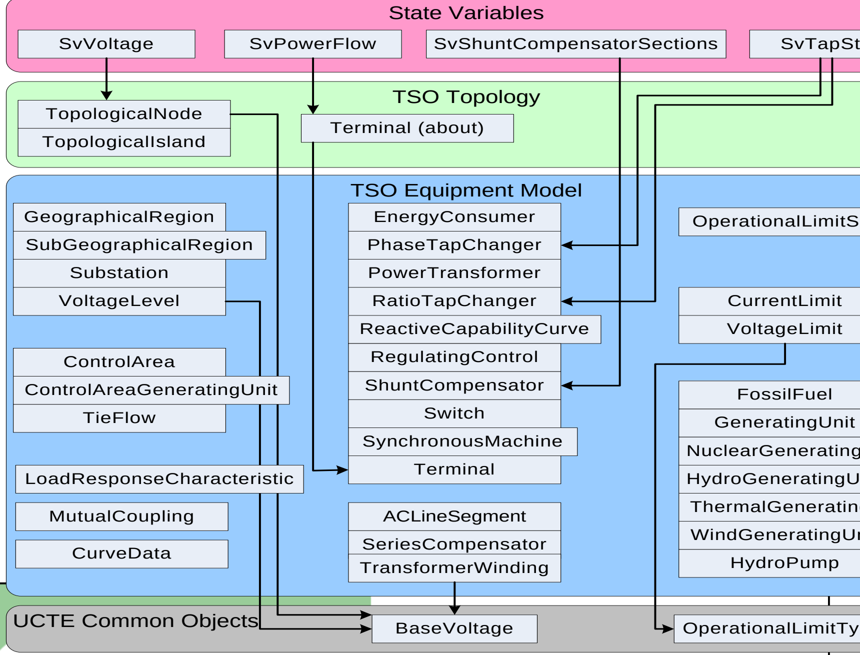
EPRI Use Case Repository Software

The EPRI Use Case Repository Software is an open source application to import use case information from the IEC use case template into and from Sparx Systems EA or other computer-aided software engineering (CASE) too ls. This software serves as the heart of the "use case process." Use cases define

◂ 12-1 ▸

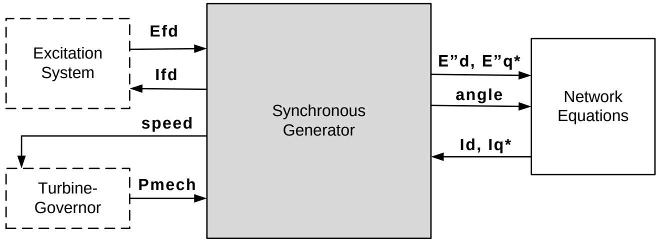






Synchronous Generator Models

For conventional power generating units (e.g., thermal, hydro, combustion turbine), a synchronous machine model represents the electrical characteristics of the generator and the mechanical characteristics of the turbine-generator rotational inertia. The standard interconnection variables between a synchronous generator model and other models are shown in the following figure and table:



* Network interface variables may differ among application programs

Synchronous Generator Interconnection Variables

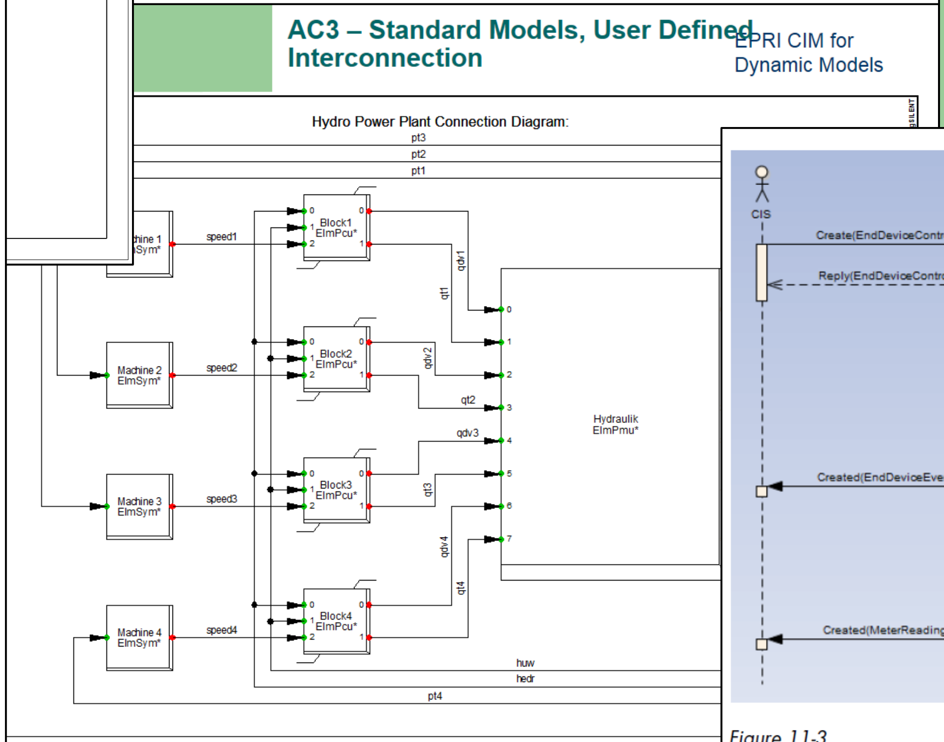
The interconnection with the electrical network equations may differ among application programs. The program only needs to know the terminal bus and generator ID to establish the correct interconnection.

Synchronous Generator Interconnection Variables

Model Type **Synchronous Generator**

Inputs:

Name	*Units*	*Description*	*Source*
Efd	p.u.	Field voltage on base of Ifag * Rfd (field resistance)	Exciter
Pmech	p.u.	Mechanical shaft power to the generator	Turbine



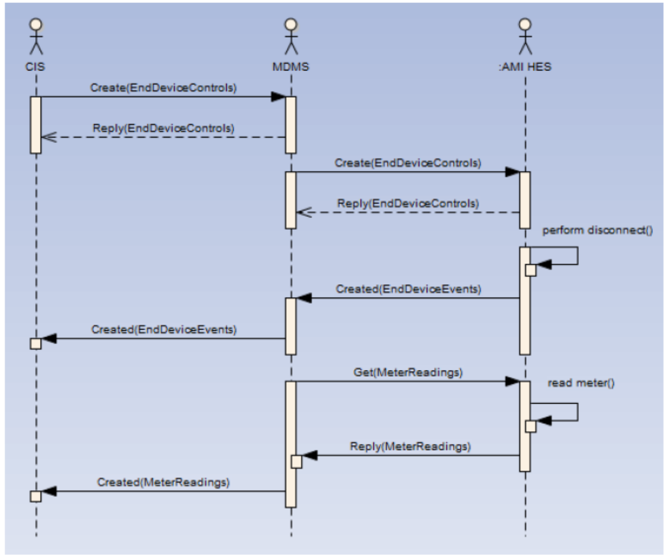
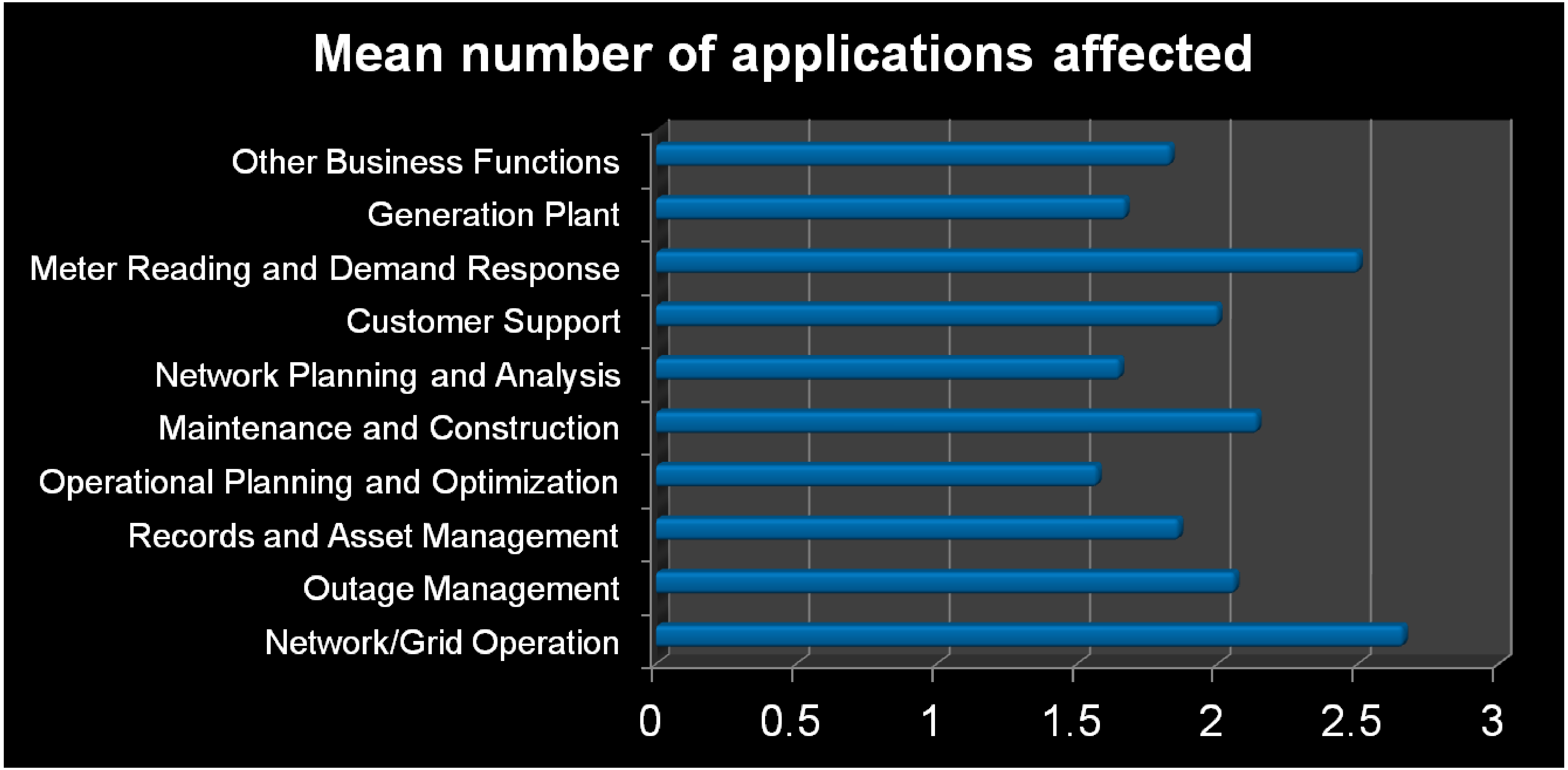


Figure 11-3
Example of message integration required for a remote discconect of a smart meter

EPRI CIM for Dynamic Models Project Report

Terry Saxton
Xtensible Solutions
May 13, 2009

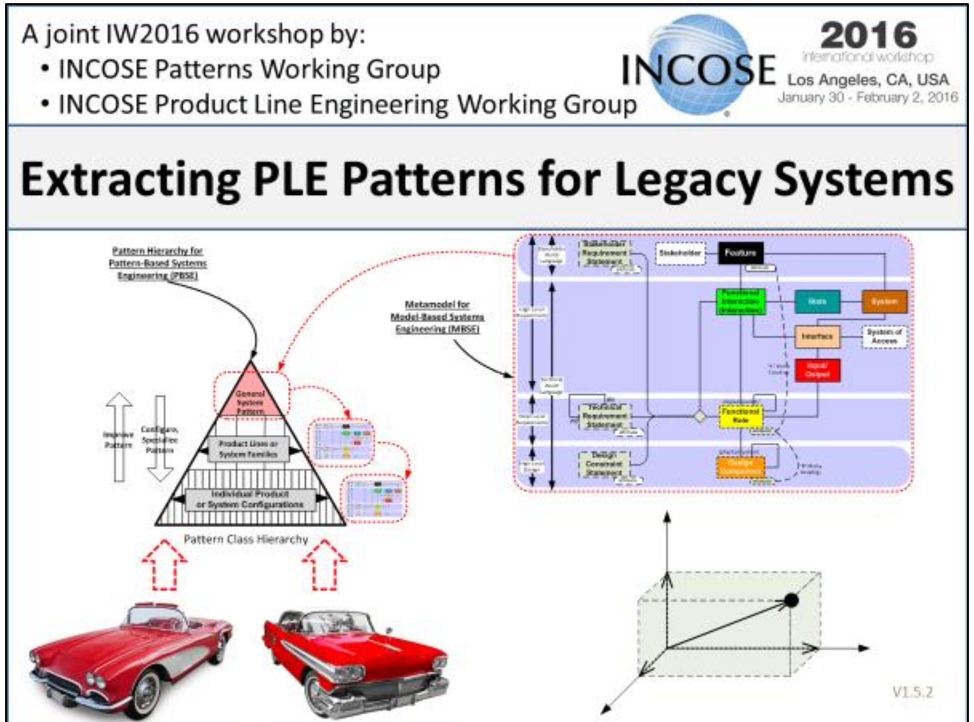
Survey of average number of applications of CIM, in survey of utilities using it (2013)



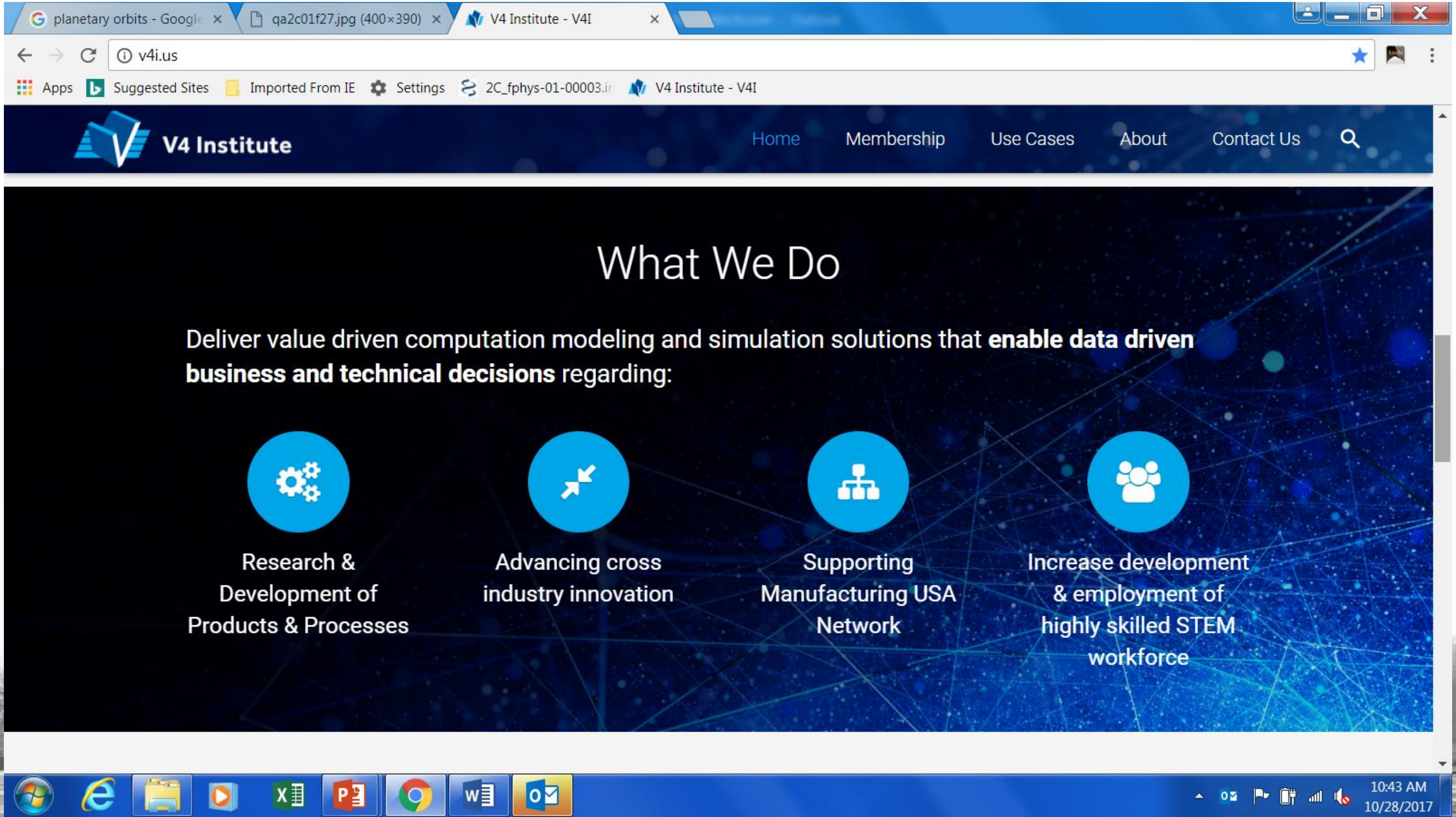
Harvesting Patterns from Legacy Descriptions

- We do not have to “model from scratch” to create MBSE Patterns that describe systems in which we have shared industry domain & public interests:
  - CIM illustrates that we need to ask the subject matter experts in these domains for what their current agreements look like.
  - The Method of Projections illustrates that we can also “harvest” formal MBSE S*Patterns from legacy documentation:

Joint project of the
INCOSE Patterns Working Group and
INCOSE PLE Working Group



V4 Institute—Member Consortium



Standards and Shared Trusted MBSE Patterns

Comparing Shared Trusted MBSE Patterns to Standards is more than an analogy:

- Formal models are appearing as <u>part of</u> formal standards, providing a more direct way to implement standards, and . . .
- Models are starting to be used to <u>generate</u> standards (Model-Based Standards Authoring, or MBSA).

Conclusions

1. The long-term leverage power of shared model-based patterns is a relentless force over time—competing enterprises, societies, take note.
2. This leverage has three power components: advantages in economics, speed, and reduction of risk.
3. Sharing such content does not preclude protecting other market-differentiating IP, and model-based patterns can specifically provide means of doing this.
4. The cost (in money, time, and risk) of establishing model credibility (Model VVUQ) is a key force for the benefit of shared, collaborative Patterns in the Public Square.

Discussion

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Speaker

Bill Schindel chairs the MBSE Patterns Working Group of the INCOSE/OMG MBSE Initiative. He is president of ICTT System Sciences, a founding member of the V4 Institute, and has practiced systems engineering for over thirty years, across multiple industry domains. Bill serves as president of the INCOSE Crossroads of America Chapter, and is an INCOSE Fellow and Certified Systems Engineering Professional. An ASME member, he is part of the ASME VV50 standards team's effort to describe the verification, validation, and uncertainty quantification of models.

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