V1.3.1

Applying Model-Based Patterns to Enhance Innovation Productivity Across the Computational Model Life Cycle

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Abstract

- The ASME VV50 Advanced Manufacturing Subcommittee's working group on the Model Life Cycle has been applying industry and systems techniques from model-based patterns methodology to enhance several aspects of productivity across the life cycle management of computational models.
  - This has included collaboration with the International Council on Systems Engineering (INCOSE) Working Group on Model-Based Patterns to represent deployable guidelines and standards in the form of configurable formal system patterns of work products, an advancement beyond the use of description of only process and procedure frequently seen in standards.
- This work recognizes that we are not only interested in models of a computational nature, describing a system of interest ("System 1"), but also simultaneously in models that represent the computational model's more effective advancement through its own life cycle:
  - a new view of the computational model itself as part of another, quite different, computational system ("System 2"), with reduced emphasis on process and procedure compared to increased emphasis on the information content of the computational model and its life environment.
- Configurable pattern methods also bring other benefits to this setting. Model-based configurable patterns may also be discovered and harvested from specific System 1 domains, as in systems of transportation, flight, medicine, and manufacturing.
  - The latter domain is of special interest to the ASME VV50 subcommittee's Advanced Manufacturing charter, while the longer list of domains has been pursued for years by the INCOSE Working Group on Model-Based Patterns. The General Manufacturing Pattern from that latter work illustrates ability to combine specific domain patterns with the general Model Characterization Pattern or more specific Model VVUQ Pattern.

Contents

Goals enabling a pervasively model-based world

1. ***<u>Scaling up</u>*** *to the population of people and volume of models and model transactions to be addressed in a world in which these will grow by orders of magnitude, overwhelming what might not otherwise be addressed by a more limited population of deeply expert model authors, model users, or model dependents--a world in which models are also being exchanged more extensively across supply chains beyond their originators.*
2. ***<u>Managing models over their entire life cycle</u>****, particularly for long-life models, including users and maintainers far from the model originator in both space (global supply chains) and time (decades).*
3. ***<u>Increasing use of what has already been learned</u>*** *(especially by others) about specific modeled product and system domains in past model cycles, so that what the same work and costly lesson discovery path is not repeatedly traveled at a cost in time, effort, and risk of model impact on human lives and other assets.*

(Goals, continued)

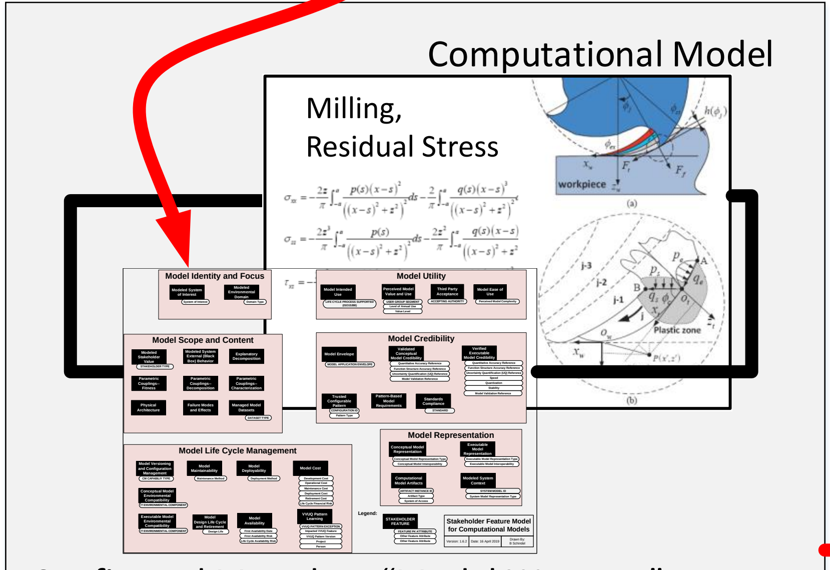
4. ***Packaging general principles as actionable assets*** *moving from already described general advice, principles, and broad guidance of text books, classes, and standards, to wider and more accessible impact by packaging as structured actionable assets (data structures, tooling, actionable learning, etc.) delivering value without requiring as deep conscious expertise in detailed practice (e.g., packaging analysis of uncertainty propagation using configurable domain specific patterns, or enabling standards that are themselves models directly downloaded and immediately used in projects, shortening adoption cycles).*
5. ***Preparing for a more building-block world****, akin to the 1960's transformation from discrete electronics to integrated circuits, but in this case for model IP. Lifting all boats by enabling more contribution of multiple players to a world of integrated systems of models, without compromise to trust.*
6. ***Unifying external metadata "wrapper" (label) across all models*** *that will continue to be more and more diverse in their internal structure, theory, tooling, domain specifics, methodologies, styles, physics vs. data origins, and other aspects, to reduce the growth rate of challenge facing regulators and other judges of the credibility of these diverse models, appearing in a growing flood.*

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.

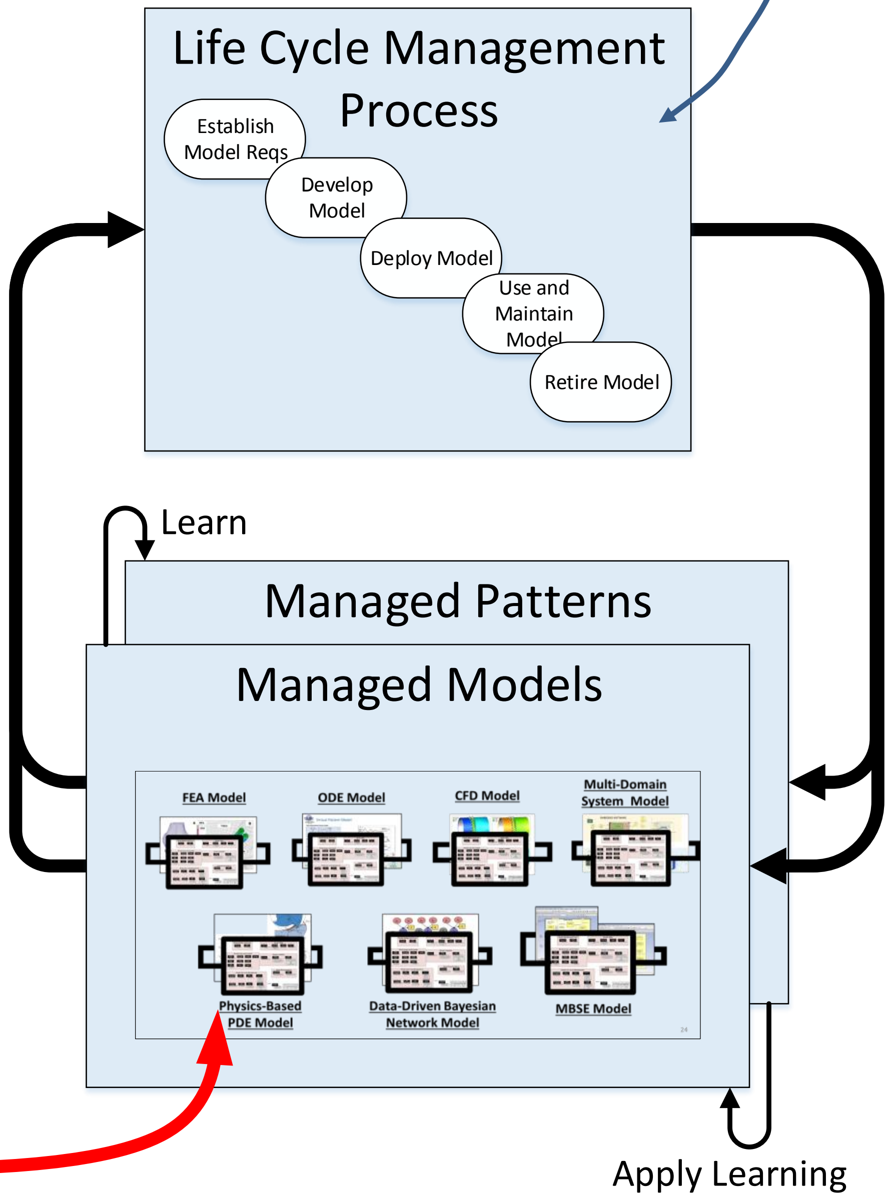
Feature Groups of Model Characterization Pattern (MCP)

Model Identity and Focus	**Model Utility**
Model Scope and Content	**Model Credibility**
Model Life Cycle Management	**Model Representation**



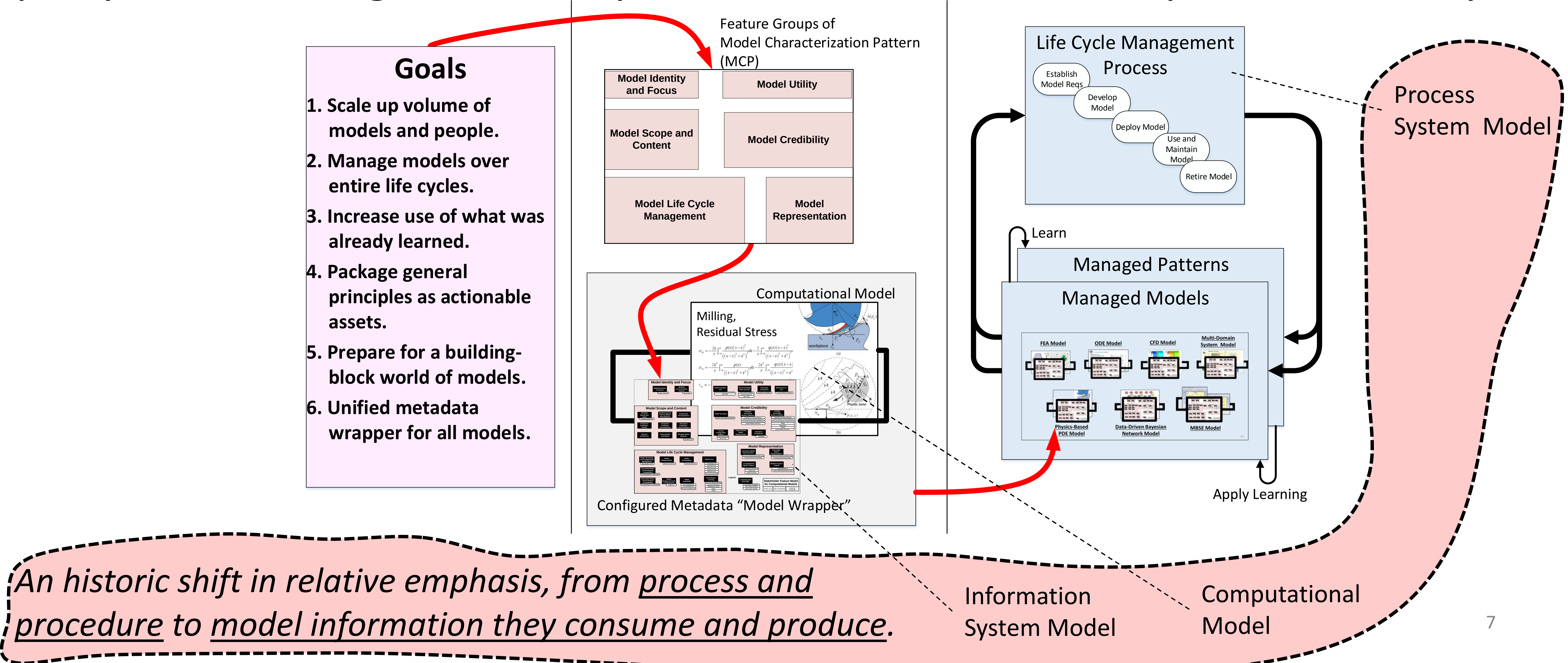
Configured Metadata “Model Wrapper”

Previous session, Laura Pullum



Infrastructure: Information Models, Processes, Automation

Pre-constructed configurable patterns, supported by standards-based third party COTS tooling from multiple sources, streamline adoption and life cycle:



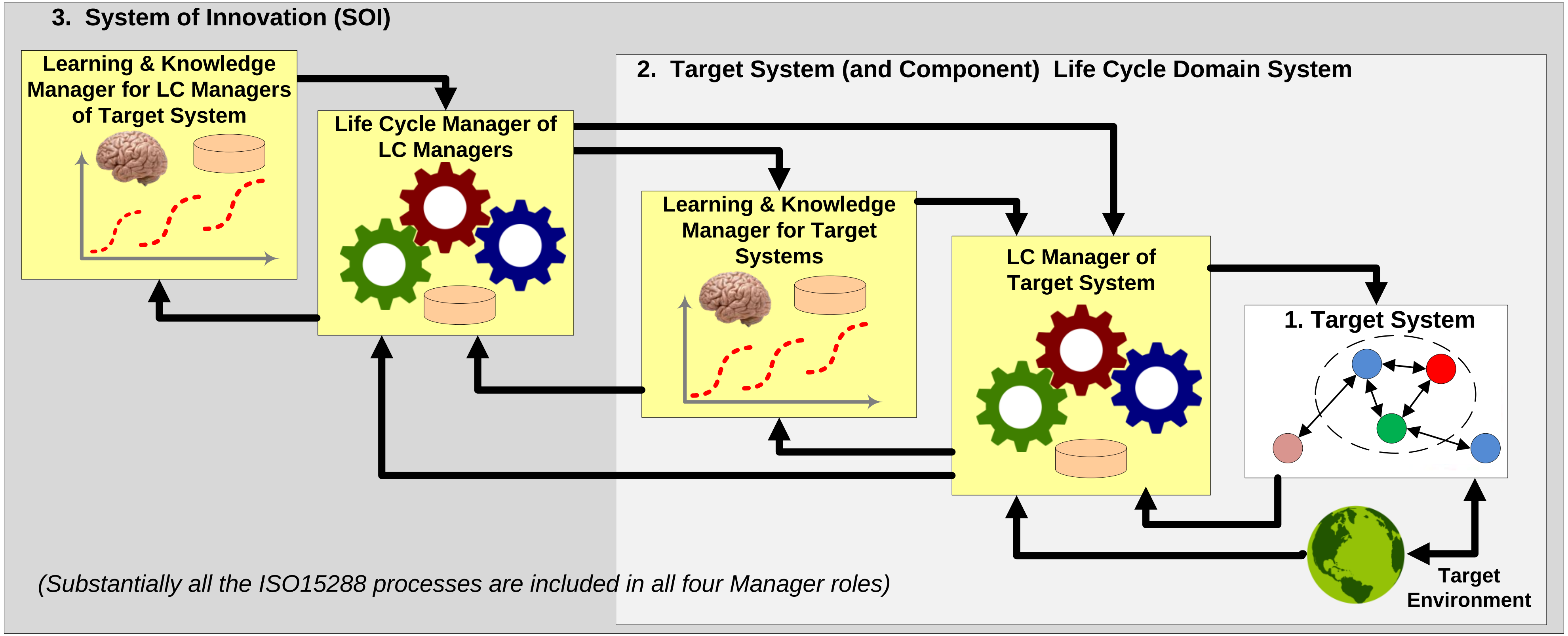
An historic shift in relative emphasis, from ***process and procedure*** *to* ***model information they consume and produce.***

Origins: A Community Effort

- ASME Model V&V 50 Subcommittee--Model Life Cycle Working Group:
  – Model VVUQ guidelines and standards authoring for establishing and maintaining computational model credibility across life cycles;
- International Council on Systems Engineering (INCOSE)--
  Model-Based Patterns Working Group:
  – Model Planning & Characterization Pattern (MCP) formalized universal model wrapper, across diverse models from INCOSE and other model-oriented societies and communities;
- V4 Institute (V4I--an NCDMM Institute):
  – Growing related virtual model capabilities across industry communities of practice;
- ICTT System Sciences:
  – Mapping to object-oriented S*Pattern, for accessibility in all S*enabled system modeling tools, including OMG SysML® and other third party COTS tooling.

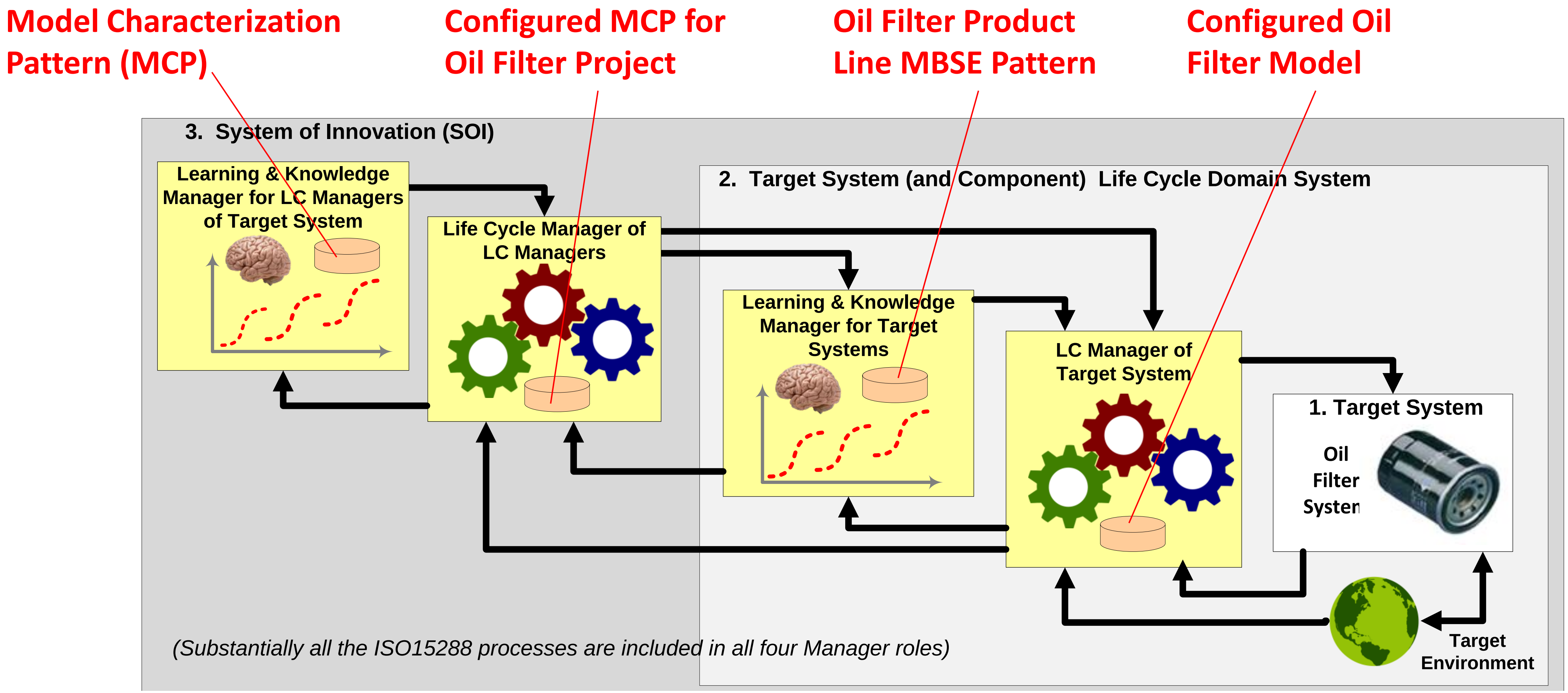
INCOSE ASELCM Pattern: Effective Group Learning, Trusted Models

(Generic agile innovation reference model: Descriptive, not prescriptive.)



- 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.

INCOSE ASELCM Pattern: Oil Filter Product Line Example



- System 1: Target system of interest, to be engineered or improved.
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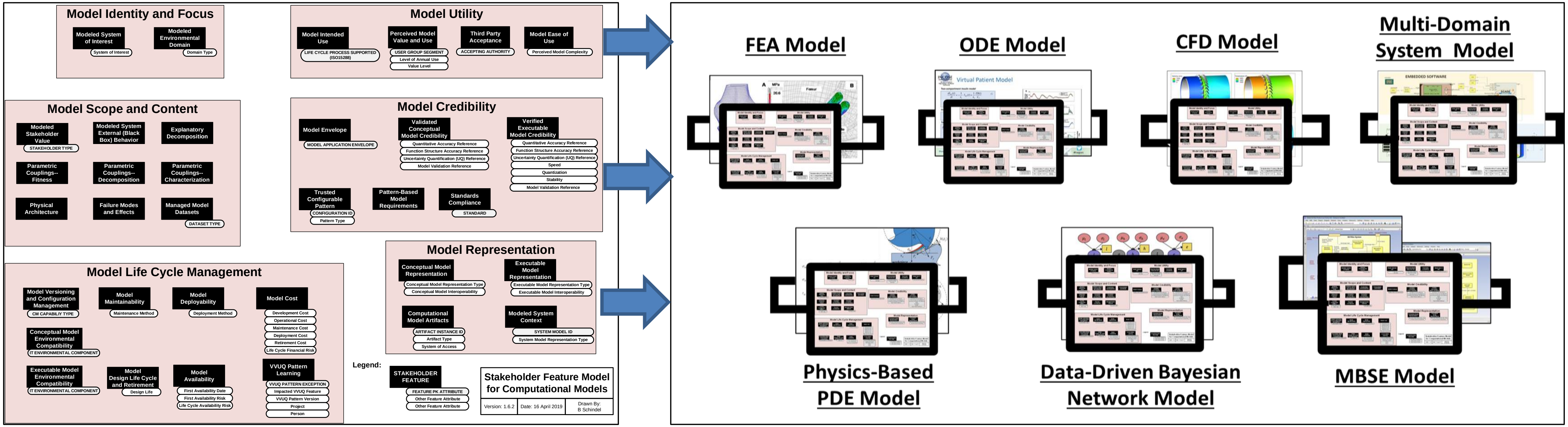
- System 3: The life cycle management systems for S2, including learning about S2.

The Model Characterization Pattern (MCP)—an S*Pattern

- A universal “wrapper” across all computational model types.
- Provides a common characterization for all models.
- Key to managing the model’s entire life cycle, including but not limited to Model VVUQ.



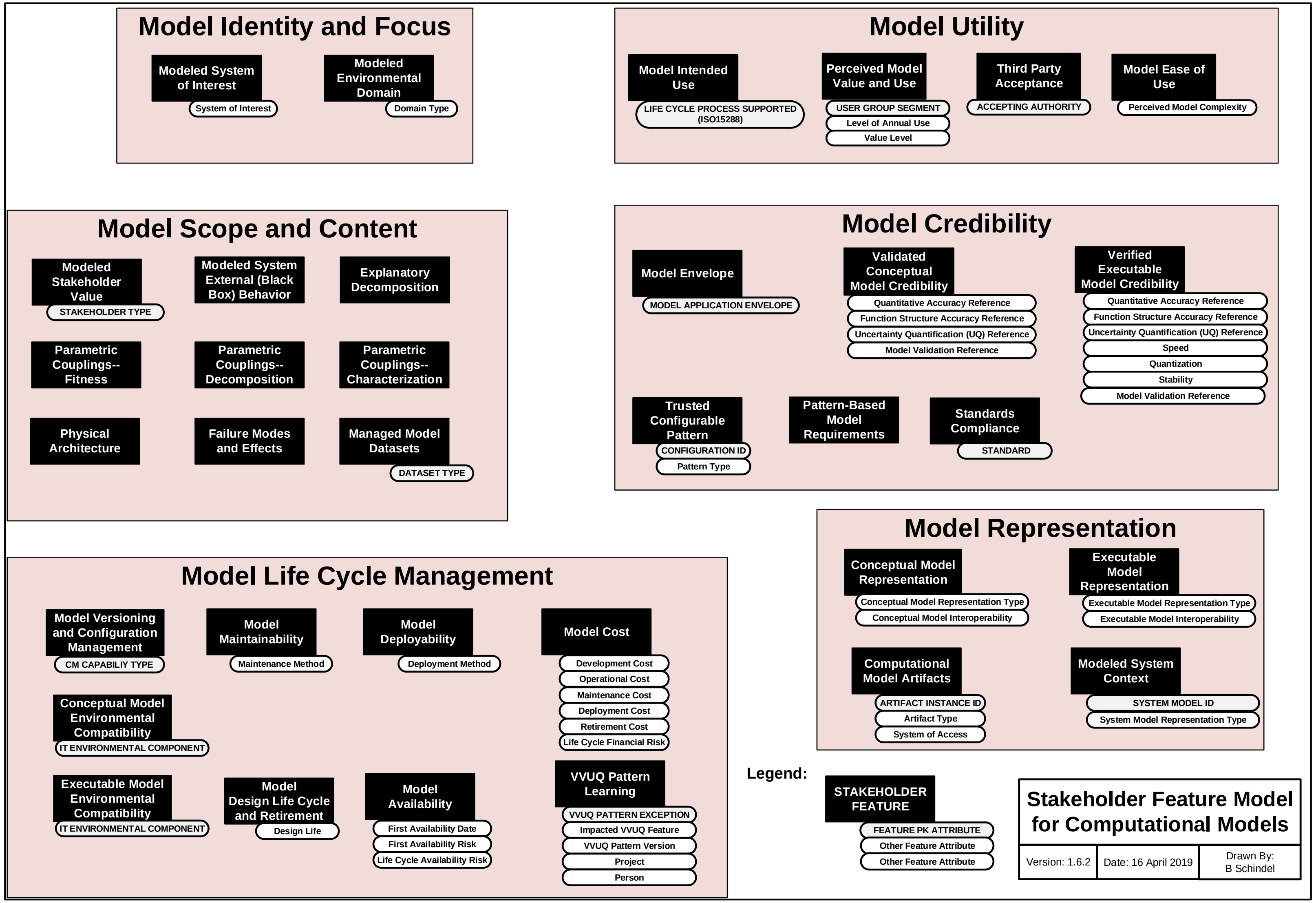
What you can do with the MCP in Computational Model Connected Projects and Enterprises

1. Rapidly generate very systematic model requirements for new or existing models, for use in model development, verification, validation, and life cycle management.
2. More effectively plan new or improved computational models, and know when you need them, versus making use of existing model assets.
3. Lower the experience threshold needed to plan and manage computational models, including model VVUQ.
4. More effectively manage large collections of diverse computational models and related information.
5. Improve access to collections of models by exposing their characteristics to users more effectively.
6. More effectively share models across supply chains and regulatory domains.

(UCP uses, continued)

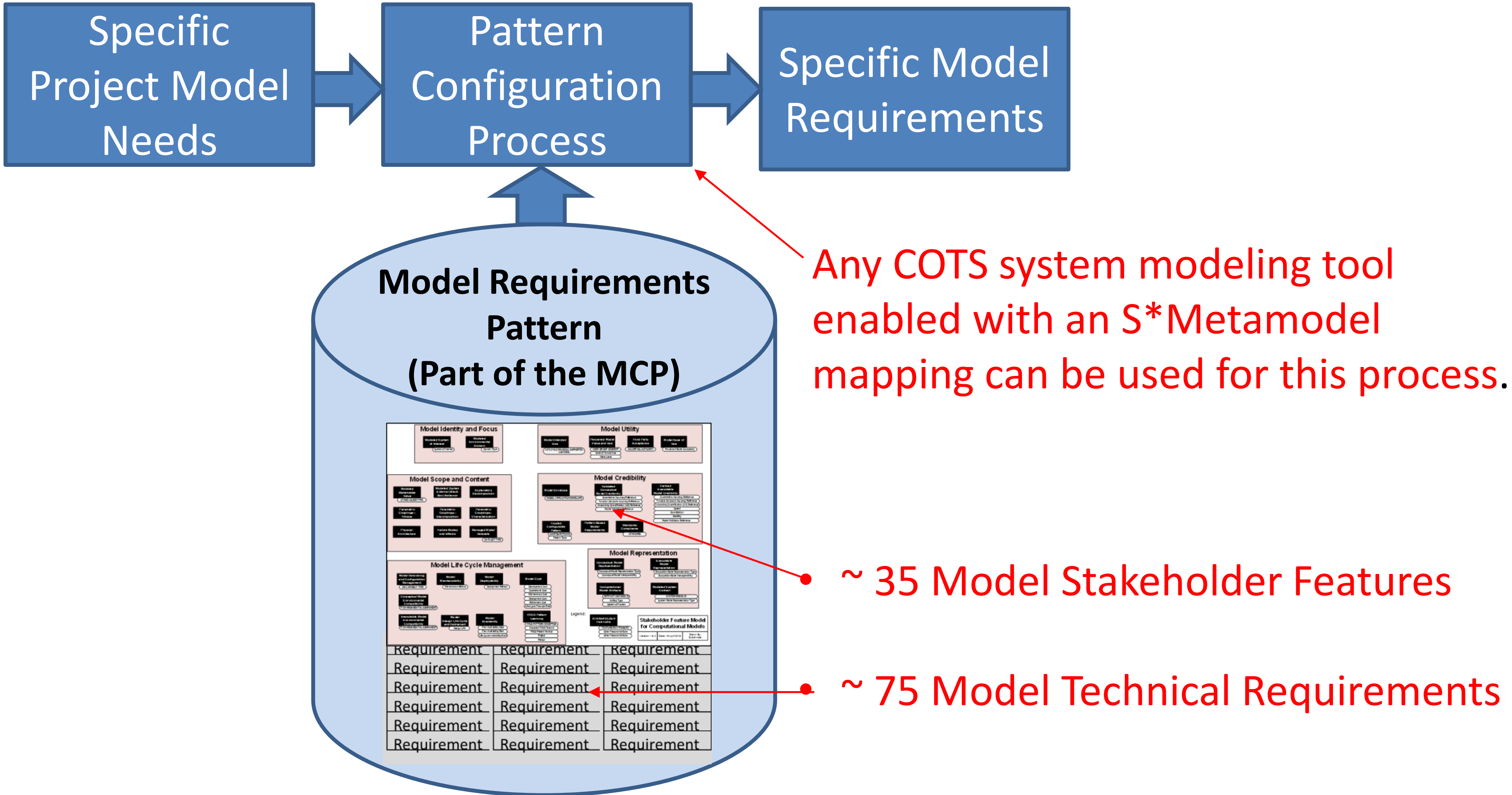
7. Lower the cost and time necessary to obtain trusted/credible models in regulated or other domains.
8. Use or manage models that were generated by others; increase the range of others who can effectively use models that you generate; reduce the likelihood of model misuse.
9. Improve the accumulation and effective use of model-based enterprise knowledge.
10. Improve the integration of model-related work across specific engineering disciplines and overall systems engineering.
11. Increase ability to manage the integration of multiple computational models (e.g., using FMI), including their integrated VVUQ.

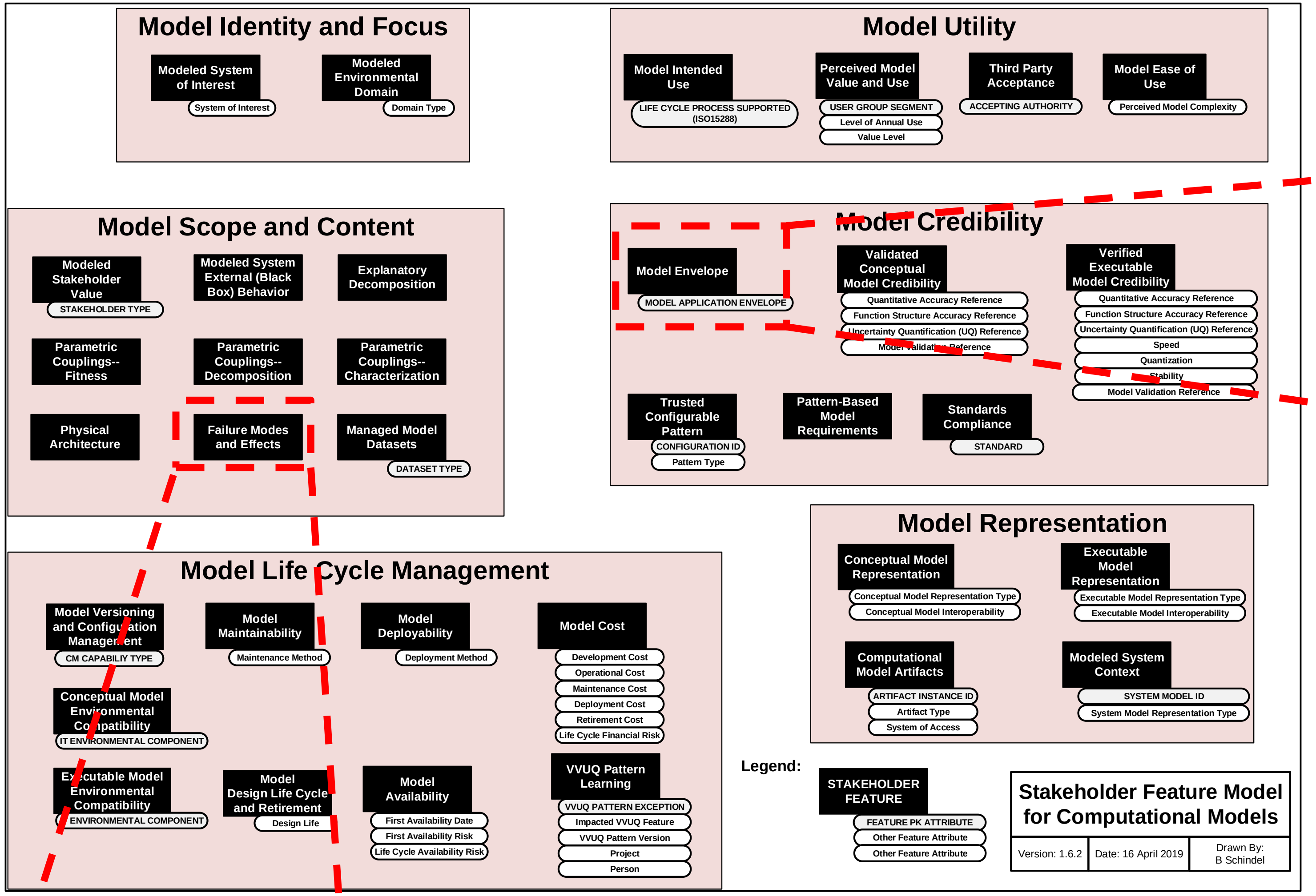
Configurable MCP Feature Groups for Models (Computational Model's Stakeholder Requirements)



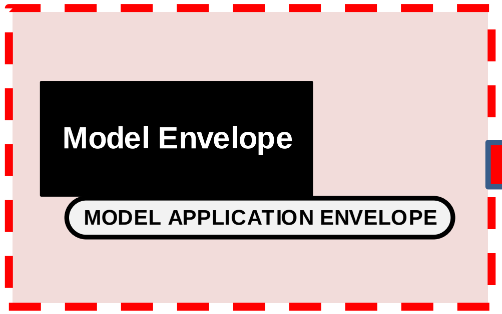
(See References for definitions.)

Configurable MCP Technical Requirements for Models





Model Feature, from Configurable VVUQ Pattern



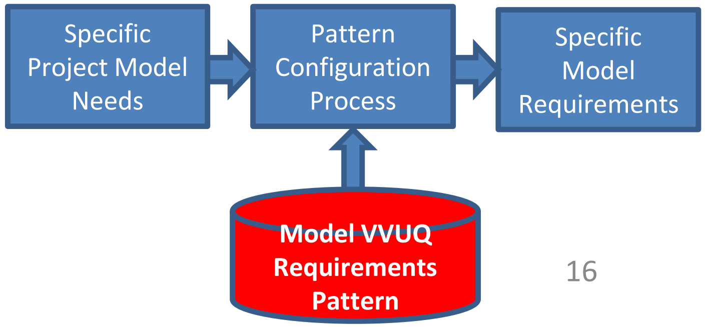
Model Requirement, from Configurable VVUQ Pattern

<u>3.1.2 Modeled Envelope, External Technical</u>: "The model shall represent the system of interest over a specified (discrete or continuous) range or envelope of technical external environment interaction configurations."

Model Feature, from Configurable VVUQ Pattern

Model Requirement, from Configurable VVUQ Pattern

<u>2.6.1 Failure Mode:</u> "The model shall include identification of component failure modes, as to underlying state leading to predicted failure."

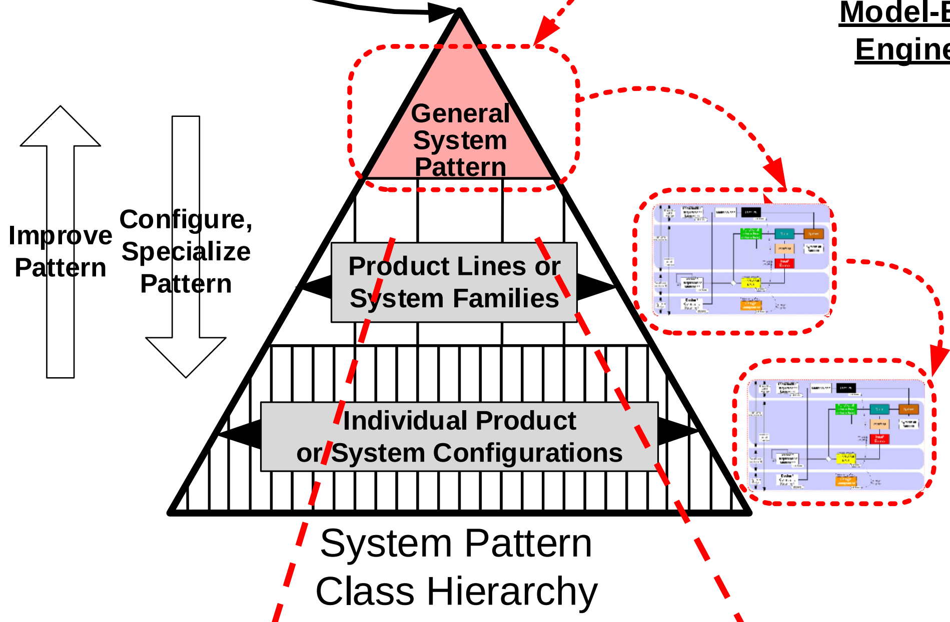


System-Level, Domain-Specific, S*Models and S*Patterns

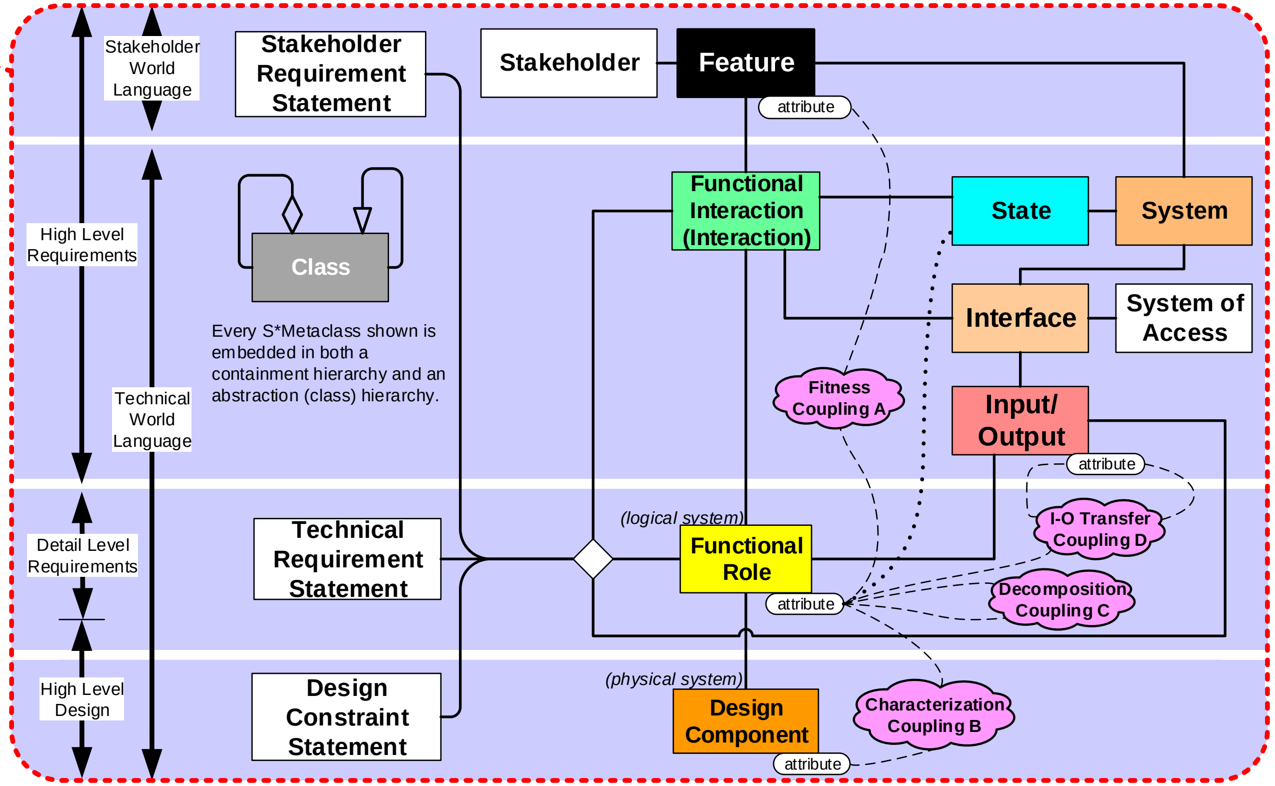
- *Past history* emphases:
  - ASME interests in Computational Models (FMEA and many others)
    - e.g., ASME VV10, VV20, etc.
  - INCOSE interests in System Models (SysML in recent years, many others)
    - e.g., INCOSE MBSE Patterns Working Group; S*Models and *Patterns
- Not quite as unrelated as believed.

System-Level, Domain-Specific, S*Models and S*Patterns

S*Pattern Hierarchy for Pattern-Based Systems Engineering (PBSE)



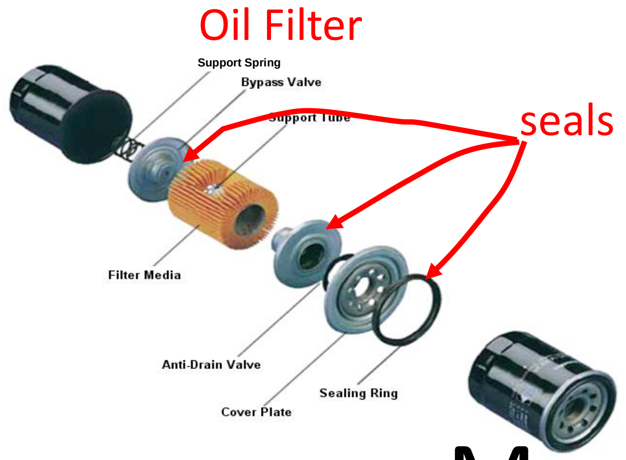
S*Metamodel for Model-Based Systems Engineering (MBSE)

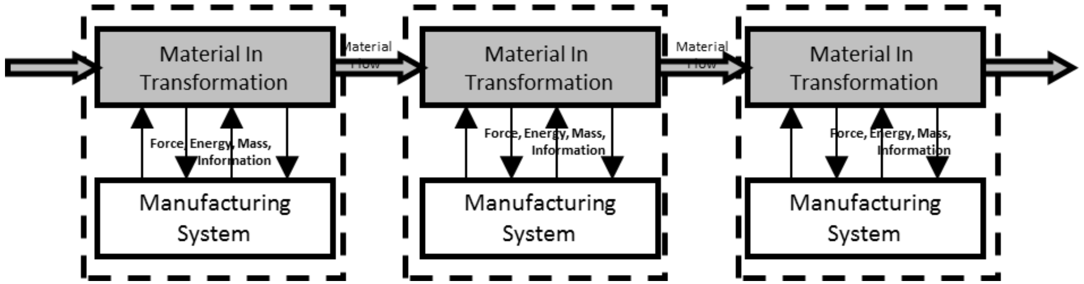


S*Metamodel informal summary pedagogical diagram
(formal S*Metamodel includes additional details.)

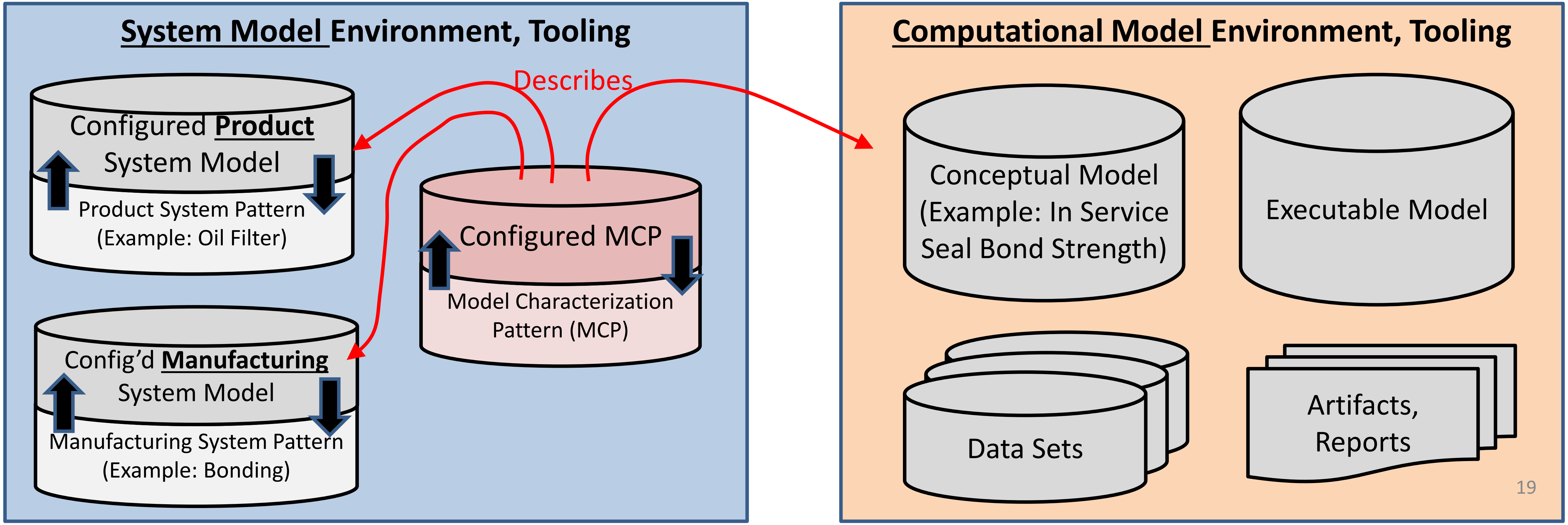
General Manufacturing S*Pattern

Product Line X S*Pattern

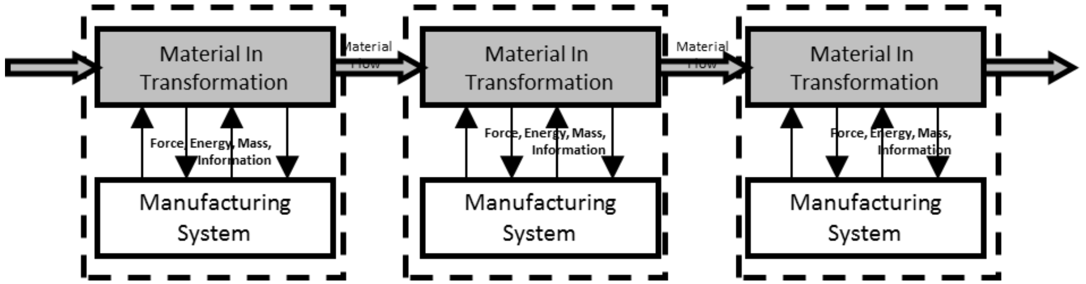


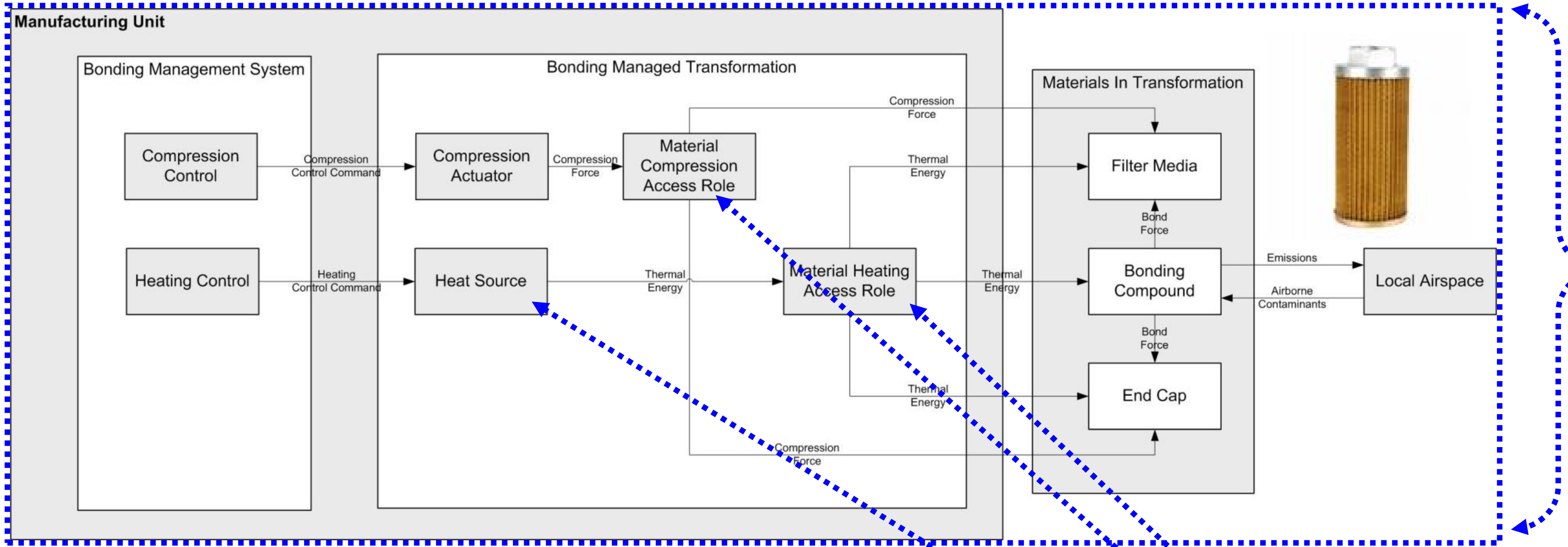


Example: Heavy Duty Oil Filter Manufacturing and Product Performance

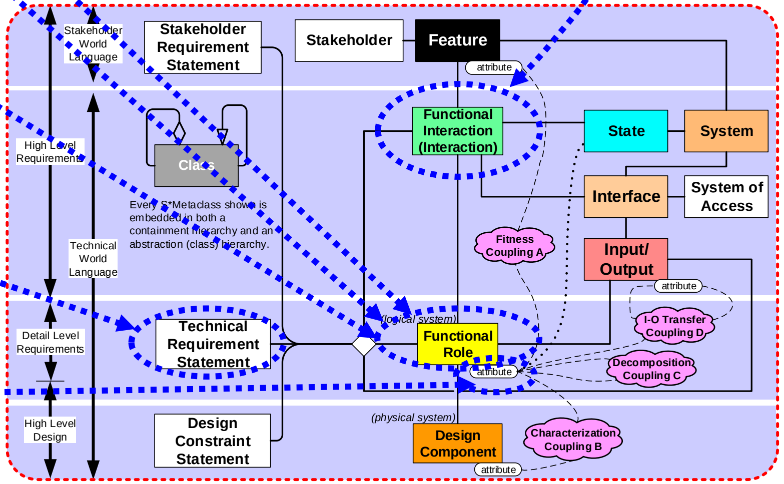


Manufacturing Interaction: Form Thermo Compression Bond





Requirements Statements may be viewed as Transfer Functions across Functional Roles, greatly improving ability to audit regular detail requirements by embedding them in the Model:



Requirement OFM-32: "The Manufacturing System shall deliver a Compression Force of [Min Bond Force] for a period of [Min Bond Time]".

Requirement OFM-33: "The Manufacturing System shall deliver Thermal Energy sufficient to maintain a bond temperature of [Min Bond Temperature] for a period of [Min Bond Time]."

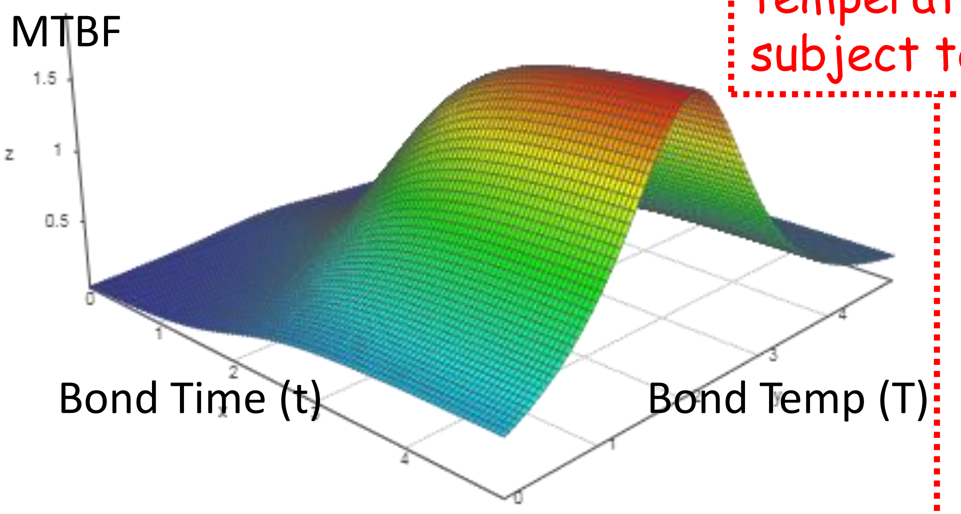
Requirement OF-51: "The Oil Filter shall operate at lubricant pressure of [Max Lubricant Pressure] with structural failure rates less than [Max Structural Failure Rate] over an in-service life of [Min Service Life]."

Parametric attribute couplings cross manufacturing process, materials, and product performance domains

The Coupling Model is a unifying framework integrating all forms of coupling:

- First principles equations
- Empirical datasets
- Graphical relations
- Data tables
- Prose statements
- Fuzzy relationships
- Other

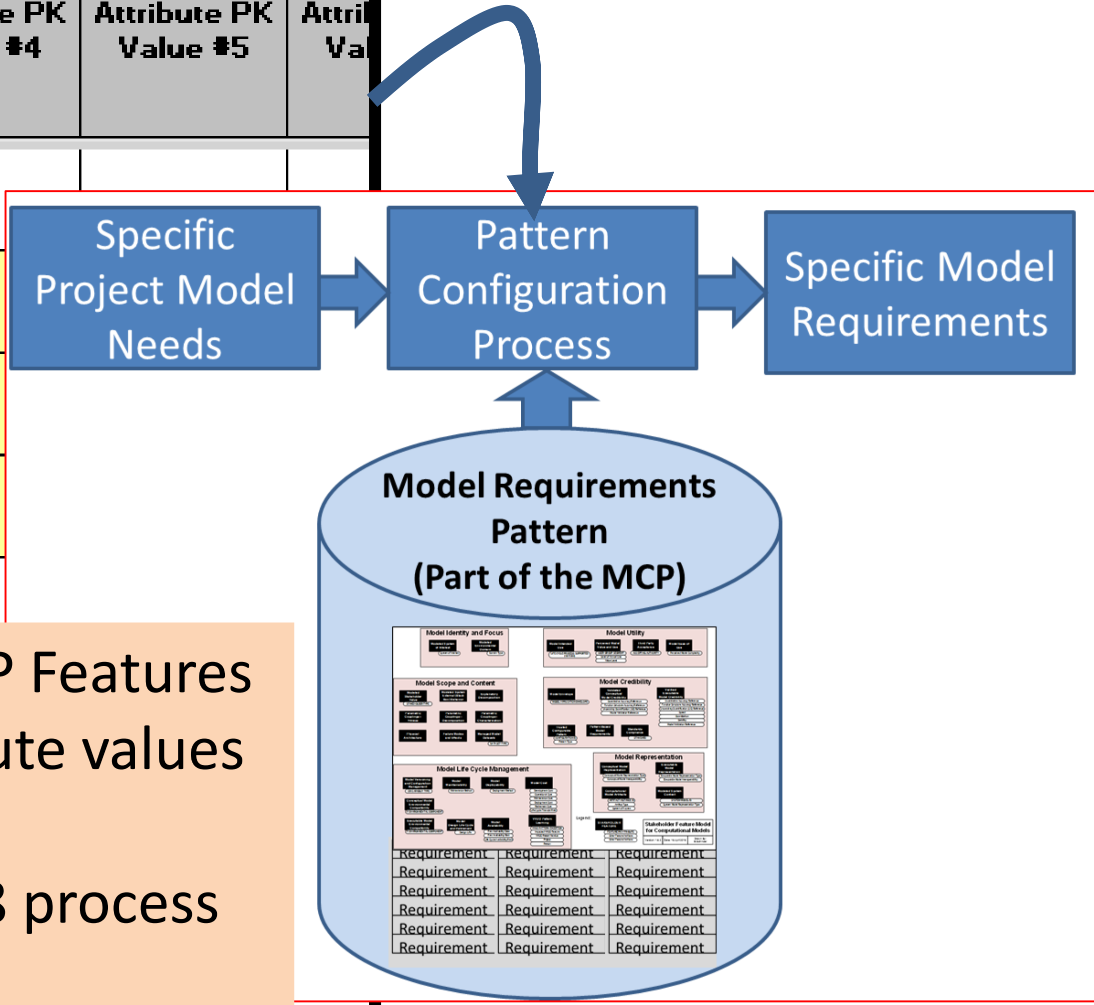
Computational model expresses oil filter product's in service MTBF under pressure, as a function of manufacturing bonding temperature and time—subject to Model VVUQ.



Configuring the MCP for a Model or Project

Populate? (YES/NO)	Feature Name	Feature Attribute Primary Key (PK) Attribute	Feature Attribute PK Value #1	Feature Attribute PK Value #2	Feature Attribute PK Value #3	Feature Attribute PK Value #4	Feature Attribute PK Value #5	Fe Attri Va
YES	**Model Ease of Use**	--						
YES	**Model Intended Use**	Life Cycle Process Supported	Verification Process					
YES	**Perceived Model Value and Use**	User Group Segment	Product Designer					
YES	**Third Party Acceptance**	Accepting Authority	FTC					
YES	**Model Credibility**	--						
YES	**Model Identity and Focus**							
YES	**Model Life Cycle Management**							
YES	**Model Representation**							
YES	**Model Scope and Content**							
YES	**Model Utility**	--						

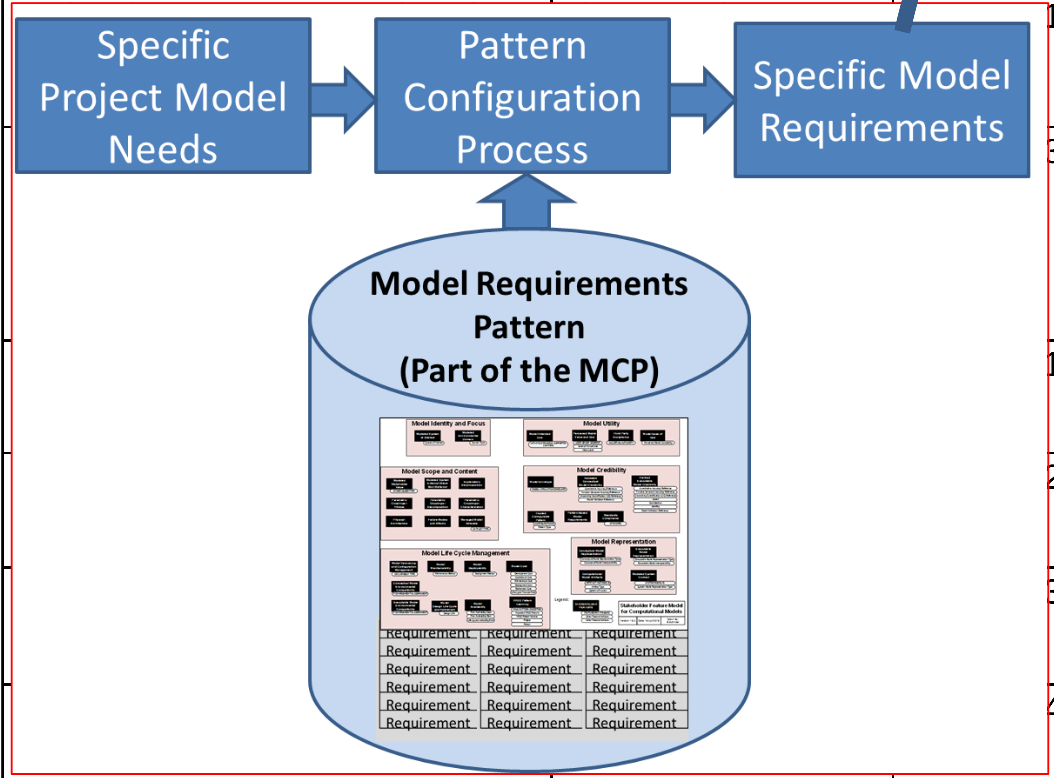
Acquisition Process
Supply Process
Project Planning Proc
Project Assessment a
Decision Management
Risk Management Pro
Configuration Manag
Information Managem



Model planner selecting which MCP Features to populate, along with their attribute values

(example shows entering ISO 15288 process areas from pull-down list)

Features	Functional Role	Req ID	Requirement
Model Availability [], Model Ease of Use[], Model Intended Use[0], Model Intended Use[Verification Process], Model Intended Use[Risk Management Process]	Virtual Model System	.1	The model user interfaces, per the [Model UI Specification] shall facilitate the efficient and effective performance of the intended purpose of the model by a user of the designated persona type.
		1	The Model shall represent the external Input-Outputs exchanged during interactions with Domain Actors, and the external Interfaces through which they are exchanged.
		3	The modeled external interactions shall include any parasitic aspects which arise from choice of internal design, materials, technologies, or solution approach but which were not otherwise required by the primary intended system purpose, where significant from a stakeholder perspective.
		1	The model shall include identification of component failure modes, as to underlying state leading to predicted failure.
		2	For each identified failure mode, the model shall include identification of cause(s) of failure mode.
		3	For each identified failure mode, the model shall include the probability of failure mode.
		4	For each identified failure mode, the model shall include the effect(s) of the mode.
Failure Modes and Effects[]	Virtual Model System	2.6.5	For each identified failure effect, the model shall include the severity of impact of the failure.
			...nodel shall represent the system of interest over a specified (discrete or ...uous) range or envelope of technical external environment interaction ...gurations.



Sampling of resulting populated Model Technical Requirements

Want to Learn More? Participate?

- For more information on:
  - ASME VV50 Subcommittee, Working Group on Computational Model Life Cycle
  - INCOSE Model-Based Patterns Working Group
  - V4 Institute

Consult the References section

References

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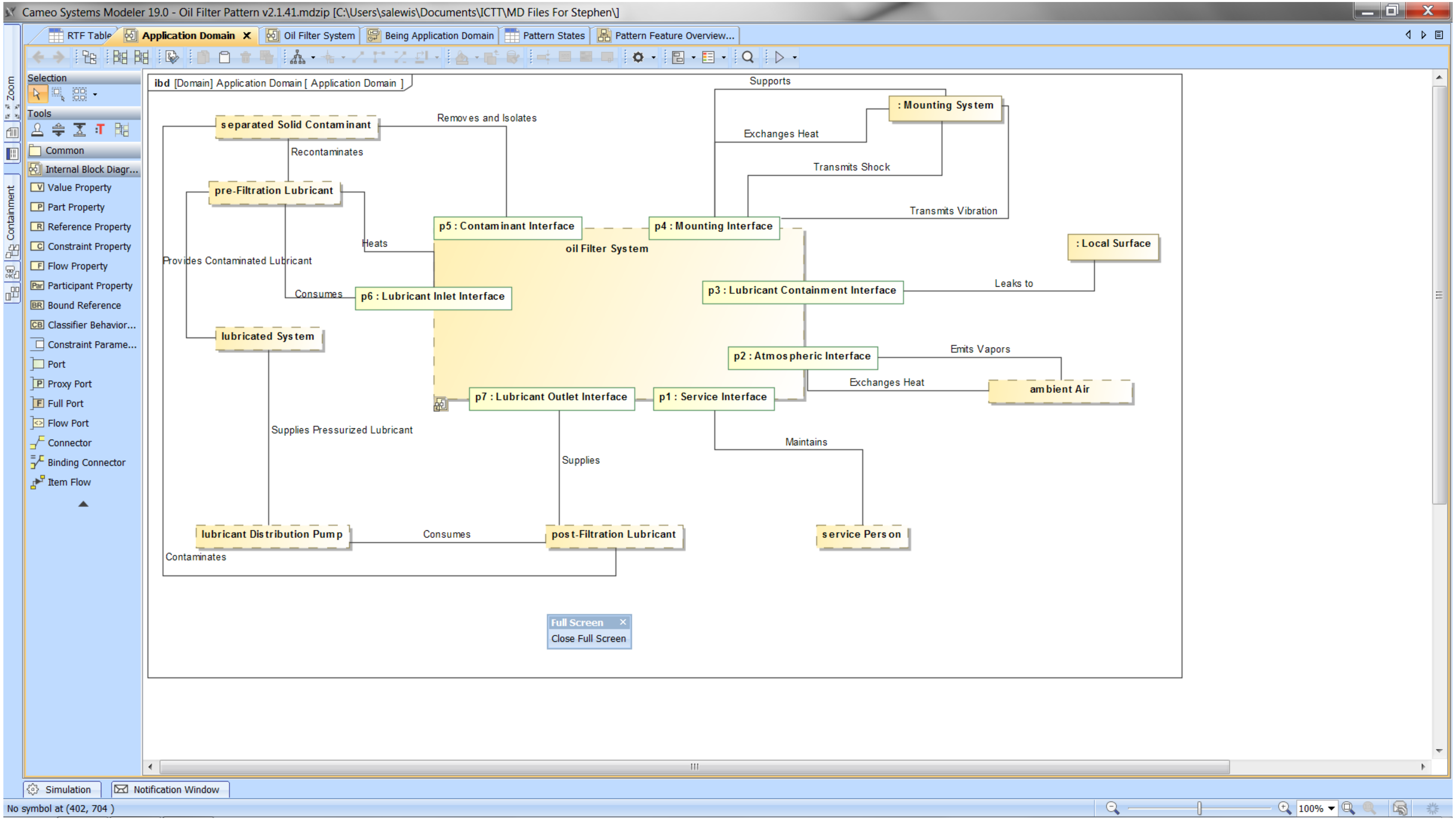
4. V4 Institute, “Trusted Models, Collaborative Learning, Accelerated Capability”, *Proc. of INCOSE 2018 Great Lakes Symposium on Systems Engineering: V4I Tutorial*, May 17, 2018, Indianapolis. Retrieve from: http://www.omgwiki.org/MBSE/lib/exe/fetch.php?media=mbse:patterns:v4i_workshop_v1.5.2.pdf

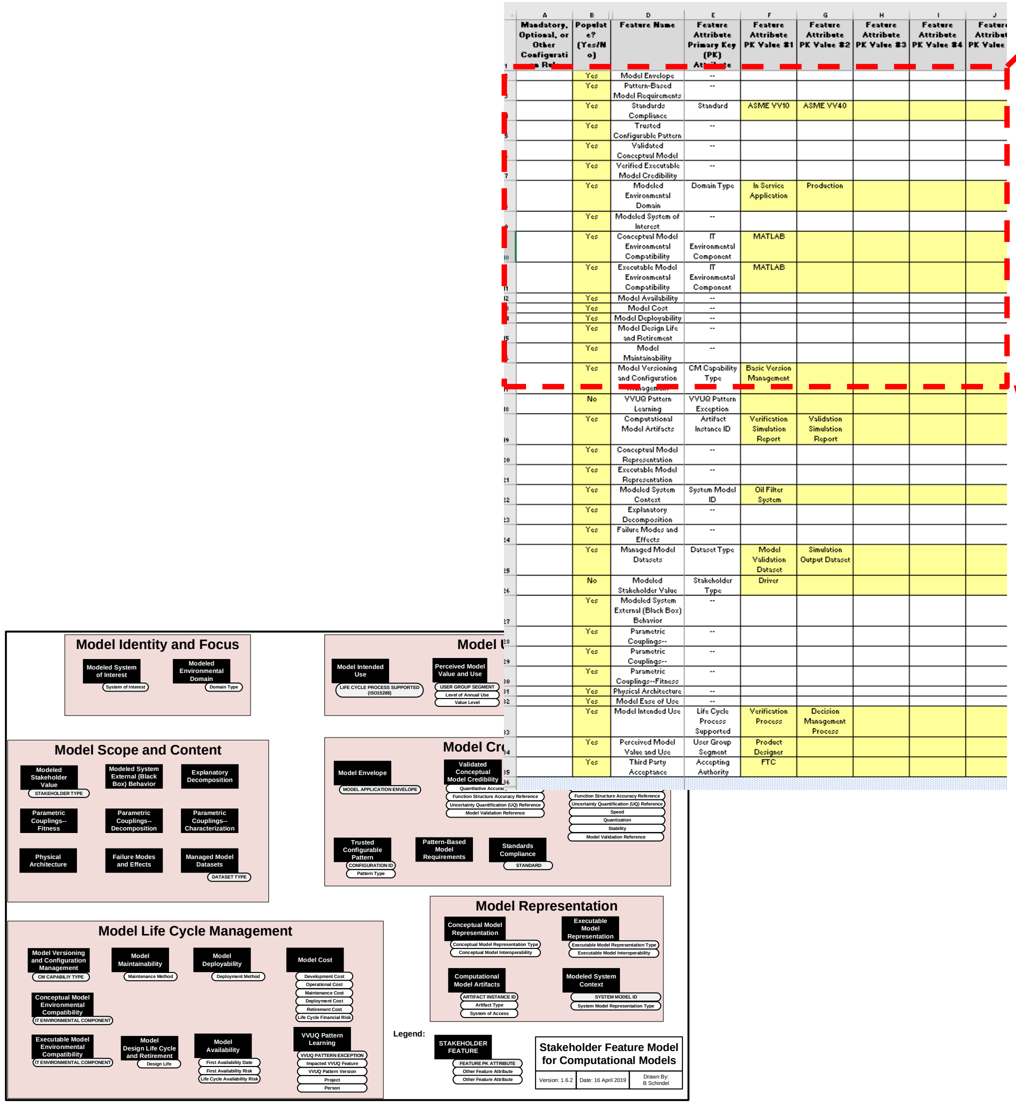
5. Schindel, W., and Dove, R., “Introduction to the INCOSE ASELCM Pattern”, *Proc. of 2016 International Symposium*, Edinburgh, UK, 2016. Retrieve from: http://www.omgwiki.org/MBSE/lib/exe/fetch.php?media=mbse:patterns:intro_to_the_aselcm_pattern_v1.6.6.pdf

6. Schindel, W., “Got Phenomena? Science-Based Disciplines for Emerging Systems Challenges”, *Proc. of the INCOSE 2016 International Symposium*, Edinburgh, UK, 2016. Retrieve from: http://www.omgwiki.org/MBSE/lib/exe/fetch.php?media=mbse:patterns:got_phenomena_v1.6.4.pdf

From SysML Model of Oil Filter Product Family



Configuring MCP Model Stakeholder Features



	A	B	D	E	F	G	H	I
1	Mandatory, Optional, or Other Configuration Rule	Populate? (Yes/No)	Feature Name	Feature Attribute Primary Key (PK) Attribute Name	Feature Attribute PK Value #1	Feature Attribute PK Value #2	Feature Attribute PK Value #3	Feature Attribute P Value #4
2		Yes	Model Envelope	--				
3		Yes	Pattern-Based Model Requirements	--				
4		Yes	Standards Compliance	Standard	ASME VV10	ASME VV40		
5		Yes	Trusted Configurable Pattern	--				
6		Yes	Validated Conceptual Model Credibility	--				
7		Yes	Verified Executable Model Credibility	--				
8		Yes	Modeled Environmental Domain	Domain Type	In Service Application	Production		
9		Yes	Modeled System of Interest	--				
10		Yes	Conceptual Model Environmental Compatibility	IT Environmental Component	MATLAB			
11		Yes	Executable Model Environmental Compatibility	IT Environmental Component	MATLAB			
12		Yes	Model Availability	--				
13		Yes	Model Cost	--				
14		Yes	Model Deployability	--				
15		Yes	Model Design Life and Retirement	--				
16		Yes	Model Maintainability	--				
17		Yes	Model Versioning and Configuration Management	CM Capability Type	Basic Version Management			
18		No	VVUQ Pattern Learning	VVUQ Pattern Exception				
19		Yes	Computational Model Artifacts	Artifact Instance ID	Verification Simulation Report	Validation Simulation Report		

ASME VV10
ASME VV20
ASME VV30
ASME VV40
ASME VV50

UserView_1

Configuring MCP Stakeholder Attribute Values

	Feature Name	PK Feature Attribute	PK Feature Attribute Value	Name of Feature Attribute #1	Value of Feature Attribute #1	Name of Feature Attribute #2	Value of Feature Attribute #2	Name of Feature Attribute #3	Value of Feature Attribute #3	Name of Feature Attribute #4	Value of Feature Attribute #4	Name of Feature Attribute #5	Value of Feature Attribute #5	Name of Feature Attribute #6	Value of Feature Attribute #6	Name of Feature Attribute #7
14	Model Availability	--	--	First Availability Date		First Availability Risk		Life Cycle Availability Risk								
15	Model Cost	--	--	Development Cost		Operational Cost		Maintenance Cost		Deployment Cost		Retirement Cost		Life Cycle Financial Risk		
16	Model Deployability	--	--	Deployment Method												
17	Model Design Life and Retirement	--	--	Design Life												
18	Model Maintainability	--	--	Maintenance Method												
19	Model Versioning and Configuration Management	CM Capability Type	Basic Version Management													
20	Computational Model Artifacts	Artifact Instance ID	Verification Simulation Report	Artifact Type		System of Access										
	Computational Model Artifacts	Artifact Instance ID	Validation Simulation Report	Artifact Type		System of Access										

Resulting Configured Computational Model Reqs

Cameo Systems Modeler 19.0 - Model Characterization Pattern 2.1.48 [MD File 1.0.4].mdzip [C:\Users\JSherey\Documents\V4I\ASME conference 201805\]

Pattern Features and Fea... | **Configured Requirements** | Pattern Functional Inter... | Pattern Logical Systems | Pattern Feature Interact... | Pattern Interaction Role... | Pattern Requirements | Pattern Feature Overview...

#	Functional Interaction	Functional Role	Name	Text	Functional Failure	Status	Rationale
1	View Conceptual Model[SOI]	Virtual Model System[]	1.1[]	The model shall identify the focal system of interest.			
2	View Conceptual Model[DOM]	Virtual Model System[]	1.2[]	The model shall represent all the external Domain Actors with which the subject system significantly interacts.			
3	View Conceptual Model[CPLNGS--FITNES]	Virtual Model System[]	2.1.4[]	For each Measure of Effectiveness (Feature Attribute), the model shall represent the quantitative coupling that determines its values versus those of the Measures of Performance upon which its valuation or fitness			
4	View Conceptual Model[EXTRN]	Virtual Model System[]	2.2.1[]	The Model shall represent the external Input-Outputs exchanged during interactions with Domain Actors, and the external Interfaces through which they are exchanged.			
5	View Conceptual Model[EXTRN]	Virtual Model System[]	2.2.2[]	The model shall represent all the significant external interactions that the system of interest has with its listed environmental actors, listing which actors are involved in each interaction.			
6	View Conceptual Model[EXTRN]	Virtual Model System[]	2.2.3[]	The modeled external interactions shall include any parasitic aspects which arise from choice of internal design, materials, technologies, or solution approach but which were not otherwise required by the primary intended system purpose, where significant from a stakeholder perspective.			
7	View Conceptual Model[EXTRN]	Virtual Model System[]	2.2.4[]	For each identified Interaction, the model shall include the dynamically changing quantities significant to the interaction, for both the System of Interest and the External Actors in the Interaction.			
8	View Conceptual Model[EXTRN]	Virtual Model System[]	2.2.5[]	For each identified Interaction, the model shall include the static or slow changing quantities characterizing the systems performance of the interaction, for both the System of Interest and the External Actors in the			
9	View Conceptual Model[EXTRN]	Virtual Model System[]	2.2.6[]	The model shall represent the different behavioral modes (states) of the system of interest that are significant to the intended use of the model.			
10	View Conceptual Model[EXTRN]	Virtual Model System[]	2.2.7[]	The model shall represent the possible (state) transitions between the modeled system behavioral modes.			
11	View Conceptual Model[EXTRN]	Virtual Model System[]	2.2.8[]	For each of its modeled behavioral modes (states), the model shall represent which external interactions the system of interest can have with its environmental actors, from the list of possible interactions.			
12	View Conceptual Model[EXTRN]	Virtual Model System[]	2.2.9[]	For each modeled interaction of the system of interest with its environment, the required external behavior of the system of interest shall be included in the model.			
13	View Conceptual Model[DECMP]	Virtual Model System[]	2.3.1[]	For each modeled external Interaction, the model shall represent the decomposition of the behavior of the system of interest into internal interactions between internal roles.			
14	View Conceptual Model[DECMP]	Virtual Model System[]	2.3.2[]	The model shall represent the internal decomposition of the system of interest functional roles until small enough to be allocated to single physical components of the modeled physical architecture.			
15	View Conceptual Model[DECMP]	Virtual Model System[]	2.3.3[]	For each modeled internal decomposed functional role, the model shall include the dynamically changing quantities significant to the related internal interactions.			
16	View Conceptual Model[DECMP]	Virtual Model System[]	2.3.4[]	For each modeled internal Interaction, the model shall include the static or slow changing quantities characterizing the system's performance of the related internal interactions.			
17	View Conceptual Model[CPLNGS--DECMP]	Virtual Model System[]	2.3.5[]	For each behavioral roles Measure of Performance, the model shall represent the quantitative coupling that determines its values versus those of the internal (decomposed) Measures of Performance upon which it depends.			
18	View Conceptual Model[PHYSARCH]	Virtual Model System[]	2.3.6[]	The model shall represent the set of physical components of the system of interest.			
19	View Conceptual Model[PHYSARCH]	Virtual Model System[]	2.3.7[]	For each modeled physical component, the model shall include attributes describing the type or identity of the physical component, indicating material type or composition, manufacturer part number, of other non-behavioral			
20	View Conceptual Model[PHYSARCH]	Virtual Model System[]	2.3.8[]	For each modeled physical component, the model shall represent its physical architectural relationships (connection, adjacency, geometry, containment hierarchy, etc.) with other physical components, defining the physical architecture of the system of interest.			
21	View Conceptual Model[CPLNGS--CHAR]	Virtual Model System[]	2.3.9[]	For each modeled physical component, the model shall represent the attribute value couplings between the identity attributes for that physical component and the behavior characterization attributes of any logical role allocated to that component by the model.			
22	View Conceptual Model[CPLNGS--CHAR]	Virtual Model System[]	2.3.10[]	The modeled internal behavioral roles and couplings shall include any parasitic aspects which arise from choice of internal design, materials, technologies, or solution approach but which were not otherwise required by the primary intended system purpose, where significant from a stakeholder perspective.			
23	View Conceptual Model[PHYSARCH]	Virtual Model System[]	2.3.11[]	For each modeled functional role (element of behavior), the model shall represent an allocation of that role to a physical component which performs or has that behavior.			
24	View Conceptual Model[PHYSARCH]	Virtual Model System[]	2.3.12[]	The model shall represent allocation of each fully decomposed functional role to not more than one physical component.			
25	View Conceptual Model[PHYSARCH]	Virtual Model System[]	2.3.13[]	For each modeled physical component, material, or equipment item, the model shall represent the allocation of all functional roles (elements of behavior) expected of that physical component, material, or equipment item.			
26	View Conceptual Model[DECMP]	Virtual Model System[]	2.3.14[]	The model shall represent the behavioral modes (states) of the internal system white box roles that are significant to the intended use of the model.			
27	View Conceptual Model[DECMP]	Virtual Model System[]	2.3.15[]	The model shall represent the possible (state) transitions between the modeled internal behavioral modes.			
28	View Conceptual Model[DECMP]	Virtual Model System[]	2.3.16[]	For each of its modeled internal modes (states), the model shall represent which interactions of internal roles may occur during such modes.			
29	View Conceptual Model[DECMP]	Virtual Model System[]	2.3.17[]	For each Modeled Black box Requirement on the system of interest the model shall provide modeled White Box Requirements traceable to and decomposing that Black Box Requirement.			
30	Configure Model from Pattern[]	Virtual Model System[]	2.4.1[]	The model shall include configurability for different cases indicated.			
31	View Datasets[Model Validation Dataset]	Virtual Model System[]	2.5.1[]	The model shall include documented example, validation, and verification data sets, including model inputs, model outputs, and model configuration.			
32	View Datasets[Model Validation Dataset]	Virtual Model System[]	2.5.2[]	The model shall include task-specific datasets from previous model executions, allowing their further use without additional model execution runs.			
33	View Datasets[Model Validation Dataset]	Virtual Model System[]	2.5.3[]	The model run data sets shall satisfy [Data Set Structural] and [Data Set Accuracy] requirements.			
34	View Conceptual Model[FMEA]	Virtual Model System[]	2.6.1[]	The model shall include identification of component failure modes, as to underlying state leading to predicted failure.			
35	View Conceptual Model[FMEA]	Virtual Model System[]	2.6.2[]	For each identified failure mode, the model shall include identification of cause(s) of failure mode.			
36	View Conceptual Model[FMEA]	Virtual Model System[]	2.6.3[]	For each identified failure mode, the model shall include the probability of failure mode.			
37	View Conceptual Model[FMEA]	Virtual Model System[]	2.6.4[]	For each identified failure mode, the model shall include the effect(s) of the mode.			
38	View Conceptual Model[FMEA]	Virtual Model System[]	2.6.5[]	For each identified failure effect, the model shall include the severity of impact of the familure.			
39	View Conceptual Model[EXTRN]	Virtual Model System[]	3.1.2[]	The model shall represent the system of interest over a specified (discrete or continuous) range or envelope of technical external environment interaction configurations.			
40	View Conceptual Model[DECMP]	Virtual Model System[]	3.1.3[]	The model shall represent the system of interest over a specified (discrete or continuous) range or envelope of physical design configurations.			

Filter is not applied. **77** rows are displayed in the table.