Attachment 1:

Patterns Working Group

Example Extracts from S*Patterns--

Virtual Verification, Validation, and Visualization Institute

- General Land Vehicle Pattern (Slide 2+)
- Generic Bracket S*Pattern (Slide 58+)
- Oil Filter S*Pattern (Slide 61+)
- Embedded Intelligence (EI) S*Pattern (Slide 82+)
- General Manufacturing Pattern (Slide 97+)
- Trusted Model Repository Reference S*Pattern (Slide 140+)

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Bill Schindel,
ICTT System Sciences
schindel@ictt.com

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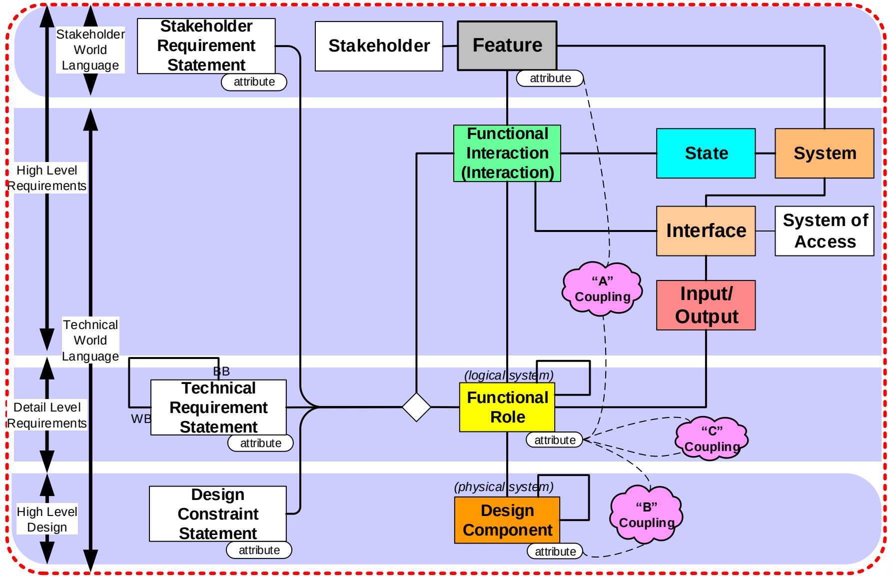
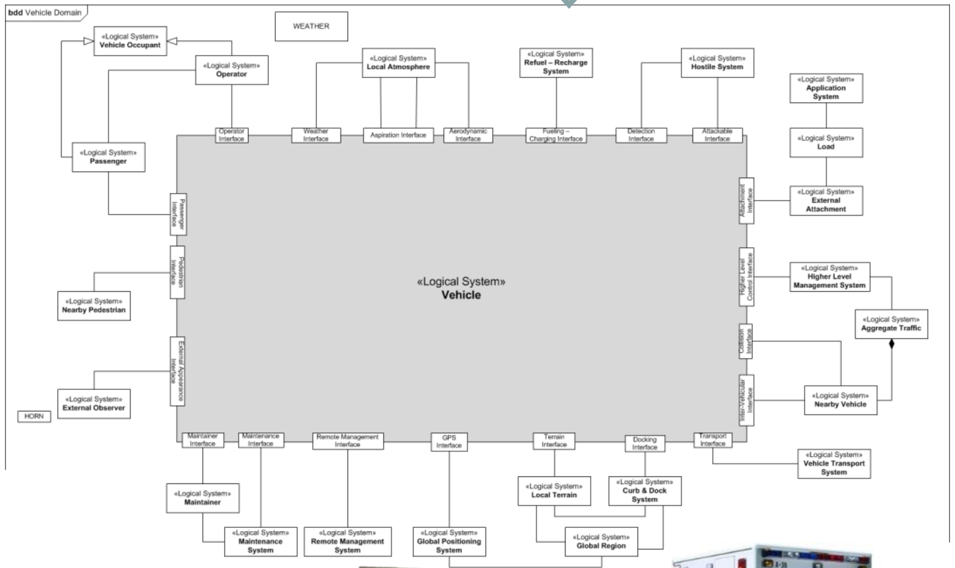
V1.2.4

Representing system patterns: An example

- S*Metamodel framework
- A Vehicle Pattern in SysML





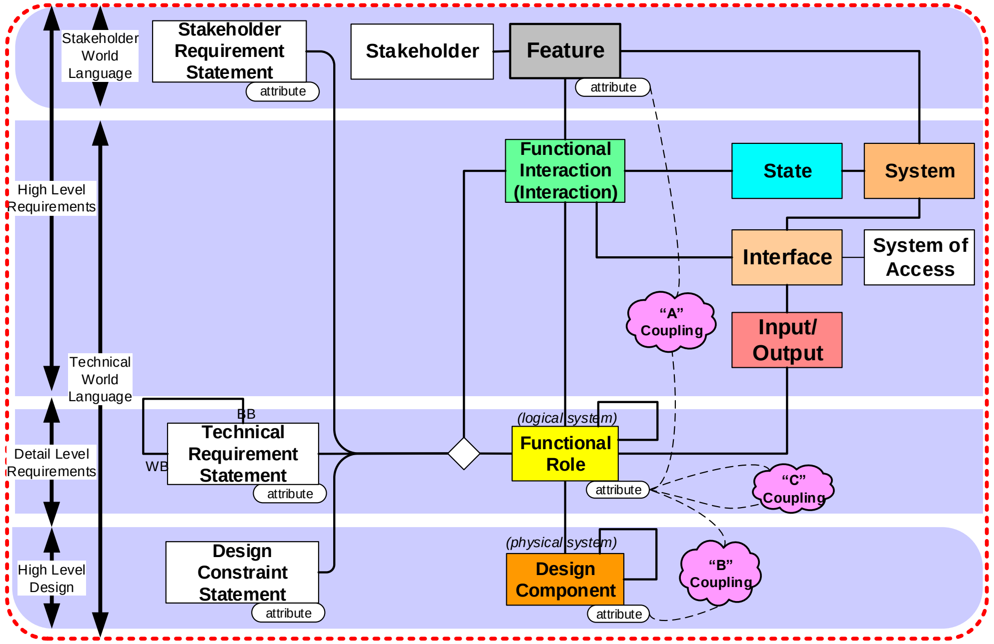
Representing System Patterns:
The S* Metamodel Framework

- What is the smallest amount of information we need to represent pattern regularities?
  - Some people have used prose to describe system regularities.
  - This is better than nothing, but usually not enough to deal with the spectrum of issues in complex systems.
- We use S* Models, which are the minimum model-based information necessary:
  - This is not a matter of modeling language—your current favorite language and tools can readily be used for S* Models.
  - The minimum underlying information classes are summarized in the S* Metamodel, for use in any modeling language.
- The resulting system model is made configurable and reusable, thereby becoming an S* Pattern.

Representing System Patterns:
The S* Metamodel Framework

- A <u>metamodel</u> is a model of other models;
  - Sets forth how we will represent Requirements, Designs, Verification, Failure Analysis, Trade-offs, etc.;
  - We utilize the (language independent) S* Metamodel from Systematica™ Methodology:
- The resulting system models may be expressed in a wide variety of third party COTS and enterprise information systems, based on S*Metamodel mappings to those environments.
- Has been applied to systems engineering in aerospace, transportation, medical, advanced manufacturing, communication, construction, other domains.

Simple summary of detailed S* Metamodel.

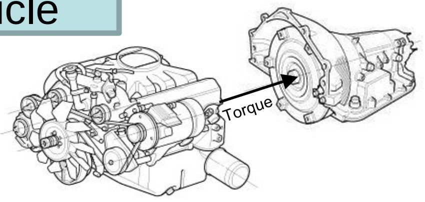


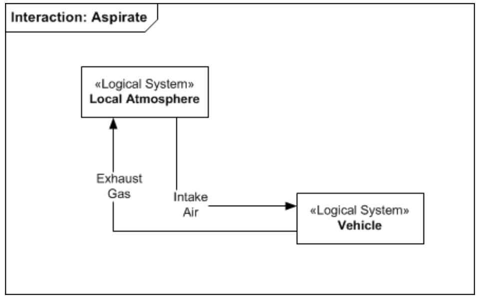
Definitions of some S* Metamodel Classes

- **System**: A collection of interacting components. Example: Vehicle; Vehicle Domain System.
- **Stakeholder**: A person or other entity with something at stake in the life cycle of a system. Example: Vehicle Operator; Vehicle Owner; Pedestrian
- **Feature**: A behavior of a system that carries stakeholder value. Example: Automatic Braking System Feature; Passenger Comfort Feature Group
- **Functional Interaction (Interaction):** An exchange of energy, force, mass, or information by two entities, in which one changes the state of the other. Example: Refuel Vehicle; Travel Over Terrain
- **Functional Role (Role):** The behavior performed by one of the interacting entities during an Interaction. Example: Vehicle Operator; Vehicle Passenger Environment Subsystem
- **Input-Output:** That which is exchanged during an interaction (generally associated with energy, force, mass, or information). Example: Fuel, Propulsion Force, Exhaust Gas

General Vehicle

Ambulance



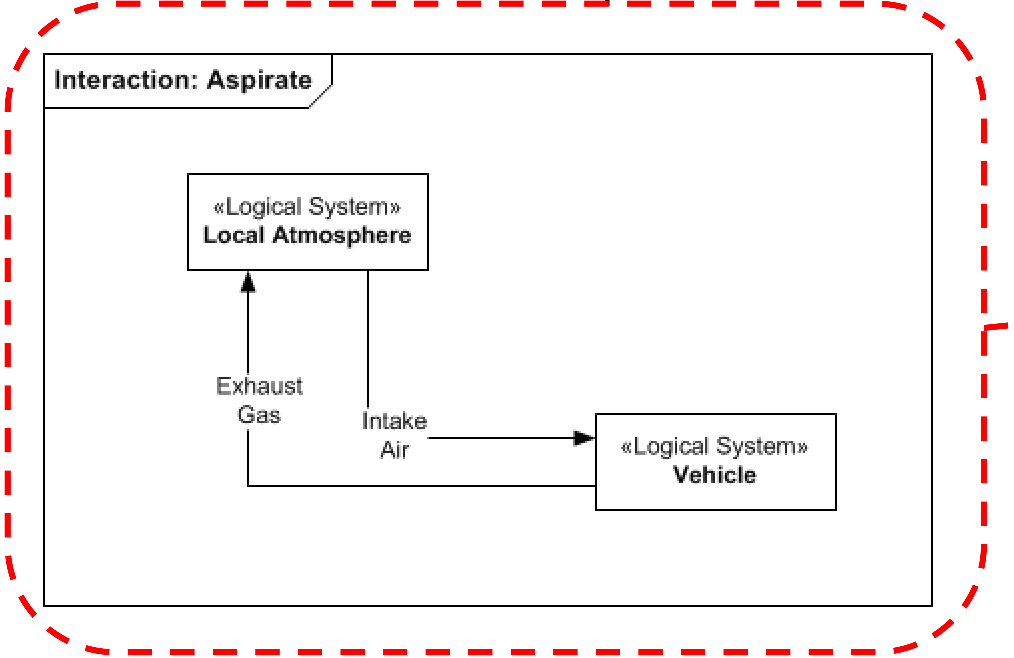


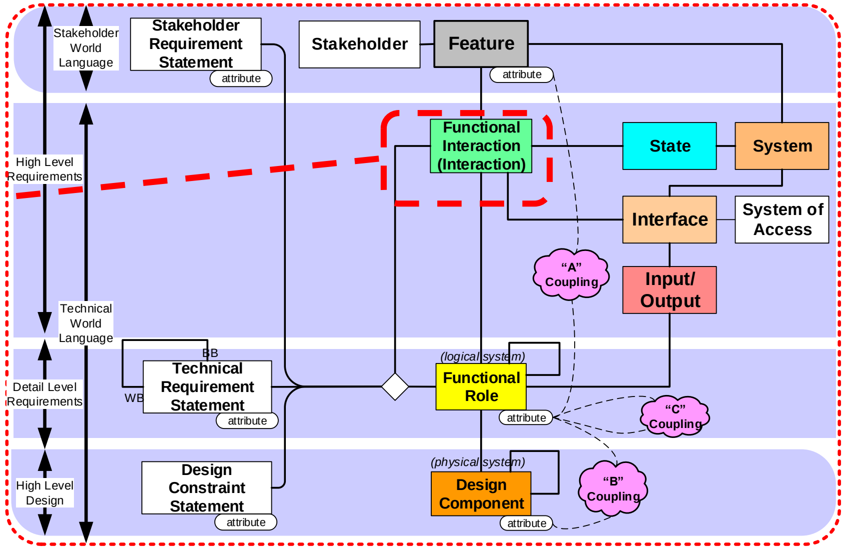
Definitions of some S* Metamodel Classes

- **System of Access:** A system which provides the means for physical interaction between two interacting entities. Examples: Fueling Nozzle-Receptacle; Grease Gun Fitting; Steering Wheel; Dashboard; Brake Peddle
- **Interface:** The association of a System (which "has" the interface), one or more Interactions (which describe behavior at the interface), the Input-Outputs (which pass through the interface), and a System of Access (which provides the means of the interaction). Examples: Operator Interface; GPS Interface
- **State:** A mode, situation, or condition that describes a System's condition at some moment or period of time. Example: Starting; Cruising; Performing Maneuvers
- **Design Component:** A physical entity that has identity, whose behavior is described by Functional Role(s) allocated to it. Examples: Garmin Model 332 GPS Receiver; Michelin Model 155 Tire
- **Requirement Statement:** A (usually prose) description of the behavior expected of (at least part of) a Functional Role. Example: "The System will accept inflow of fuel at up to 10 gallons per minute without overflow or spillage."

Physical Interactions: At the heart of S* models

- S* models represent Interactions as explicit objects:
  - Goes to the heart of 300 years of natural science of systems as a foundation for engineering, including emergence.
  - All physical laws of science are about interactions in some way.
  - All functional requirements are revealed as external interactions (!)



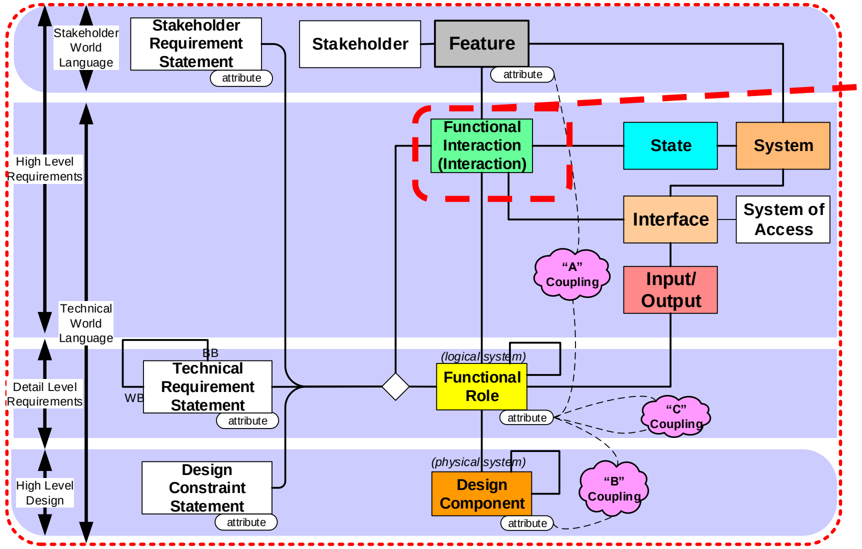


- Other Metamodel parts: See the Pattern example .

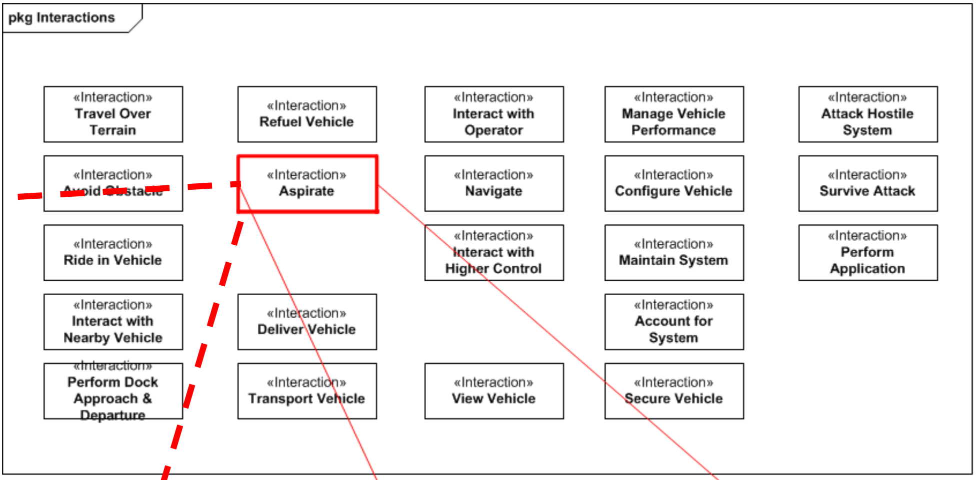
Physical Interactions: At the heart of S* models

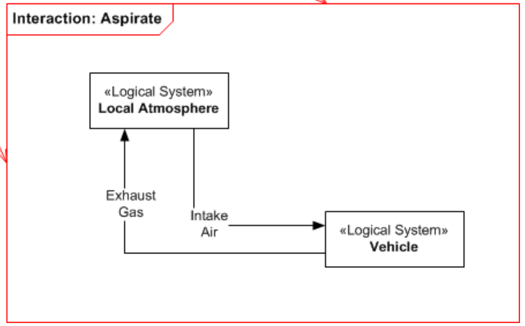
- S* models represent <u>Physical Interactions</u> as explicit objects:

Metamodel



Vehicle Pattern Interactions





Interaction Diagram

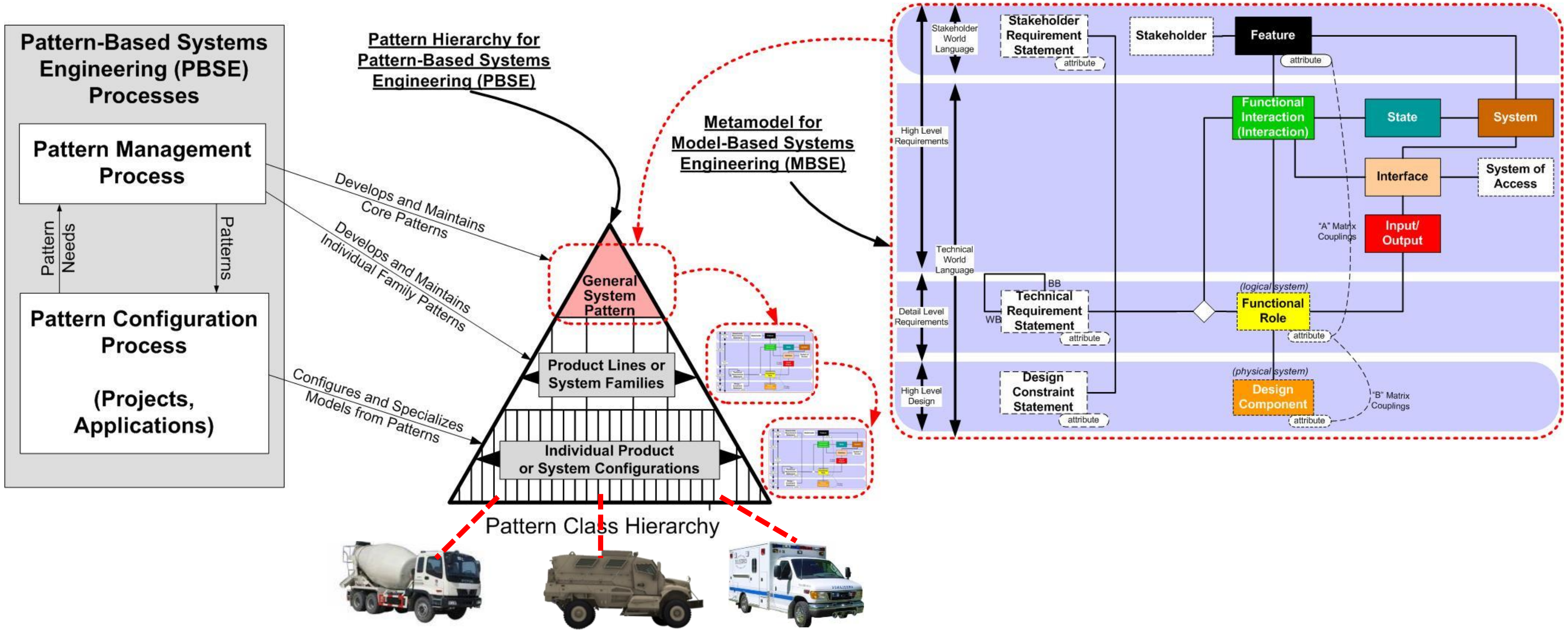
<u>**Aspirate**</u>: The interaction of the vehicle with the Local Atmosphere, through which air is taken into the vehicle for operational purposes, and gaseous emissions are expelled into the atmosphere.

Pattern-based systems engineering (PBSE)

- Model-based Patterns:
  - In this approach, Patterns are reusable, configurable S* models of families (product lines, sets, ensembles) of systems.
  - A Pattern is not just the physical product family—it includes its behavior, decomposition structure, failure modes, and other aspects of its model.
- These Patterns are ready to be configured to serve as Models of individual systems in projects.
- Configured here is specifically limited to mean that:
  - Pattern model components are populated / de-populated, and
  - Pattern model attribute (parameter) values are set
  - both based on Configuration Rules that are part of the Pattern.
- Patterns based on the same Metamodel as “ordinary” Models

Pattern-based systems engineering (PBSE)

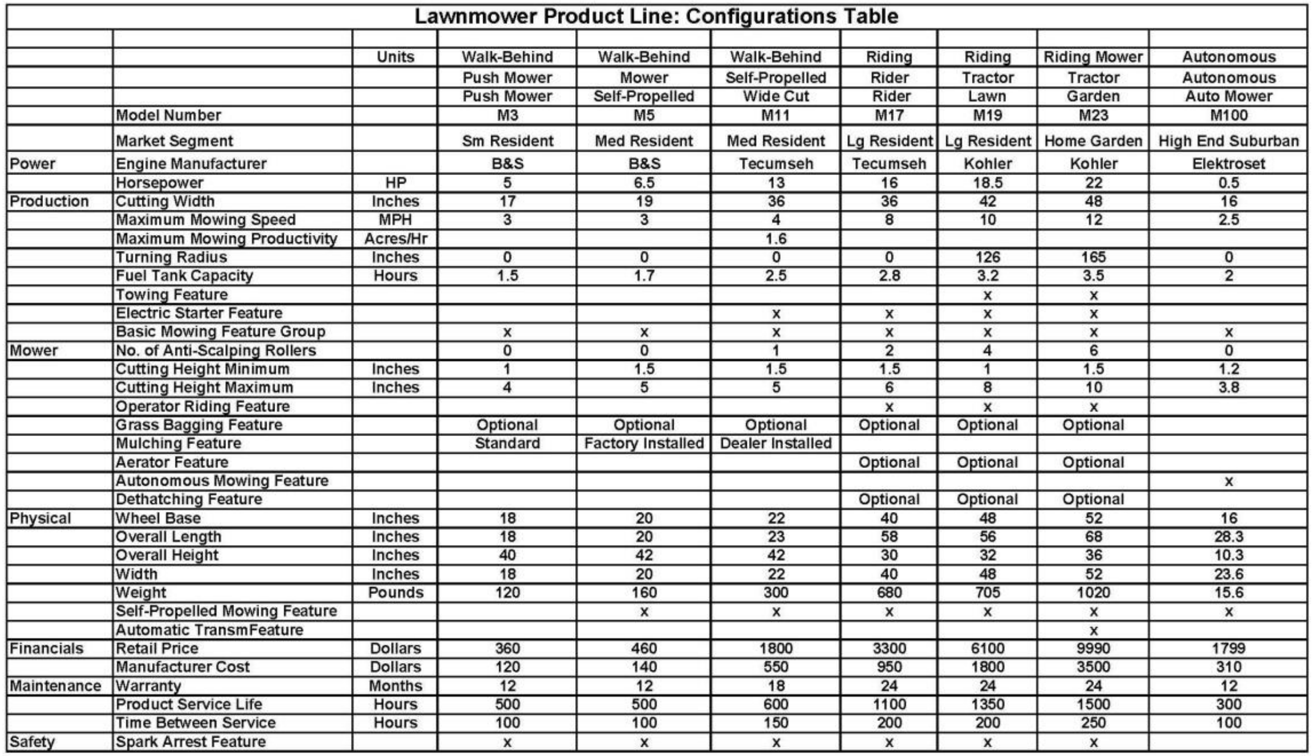
- Pattern-Based Systems Engineering (PBSE) has two overall processes:
  - **Pattern Management Process**: Creates the general pattern, and periodically updates it based on application project discovery and learning;
  - **Pattern Configuration Process**: Configures the pattern into a specific model configuration (e.g., a new product) for application in a project.



We'll discuss examples from both processes in this tutorial.

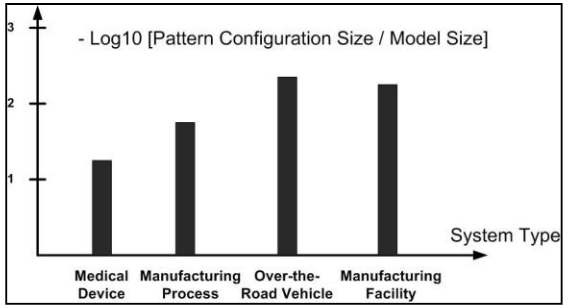
Pattern configurations

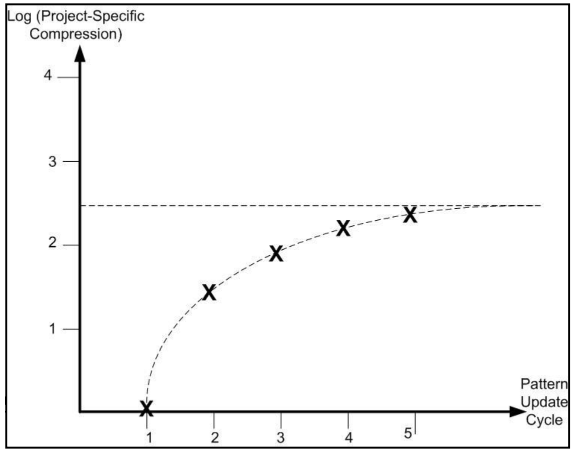
- A table of configurations illustrates how patterns facilitate compression;
- Each column in the table is a compressed system representation with respect to ("modulo") the pattern;
- The compression is typically very large;
- The compression ratio tells us how much of the pattern is variable and how much fixed, across the family of potential configurations.



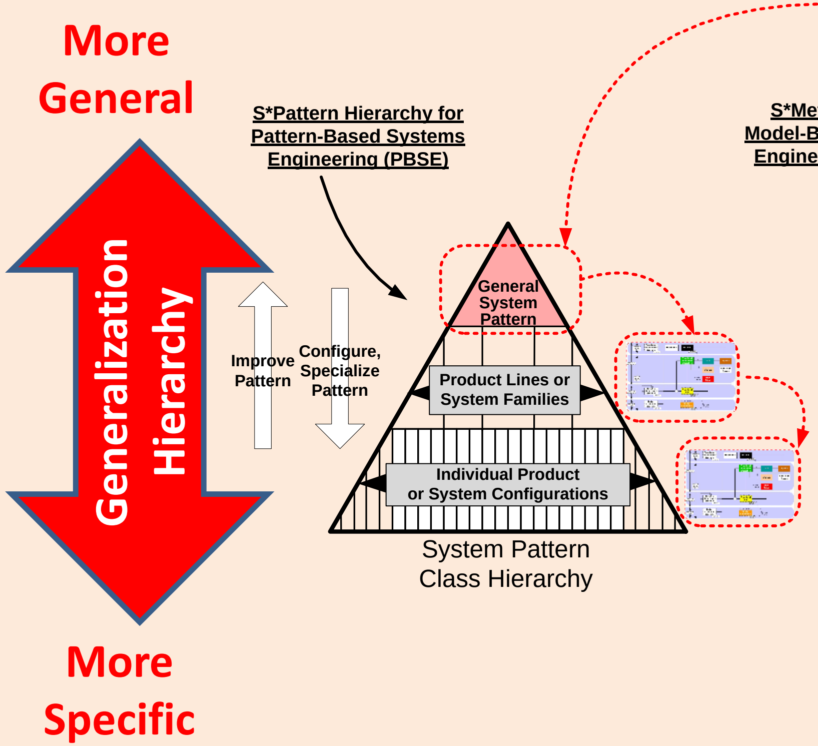
Lawnmower Product Line: Configurations Table

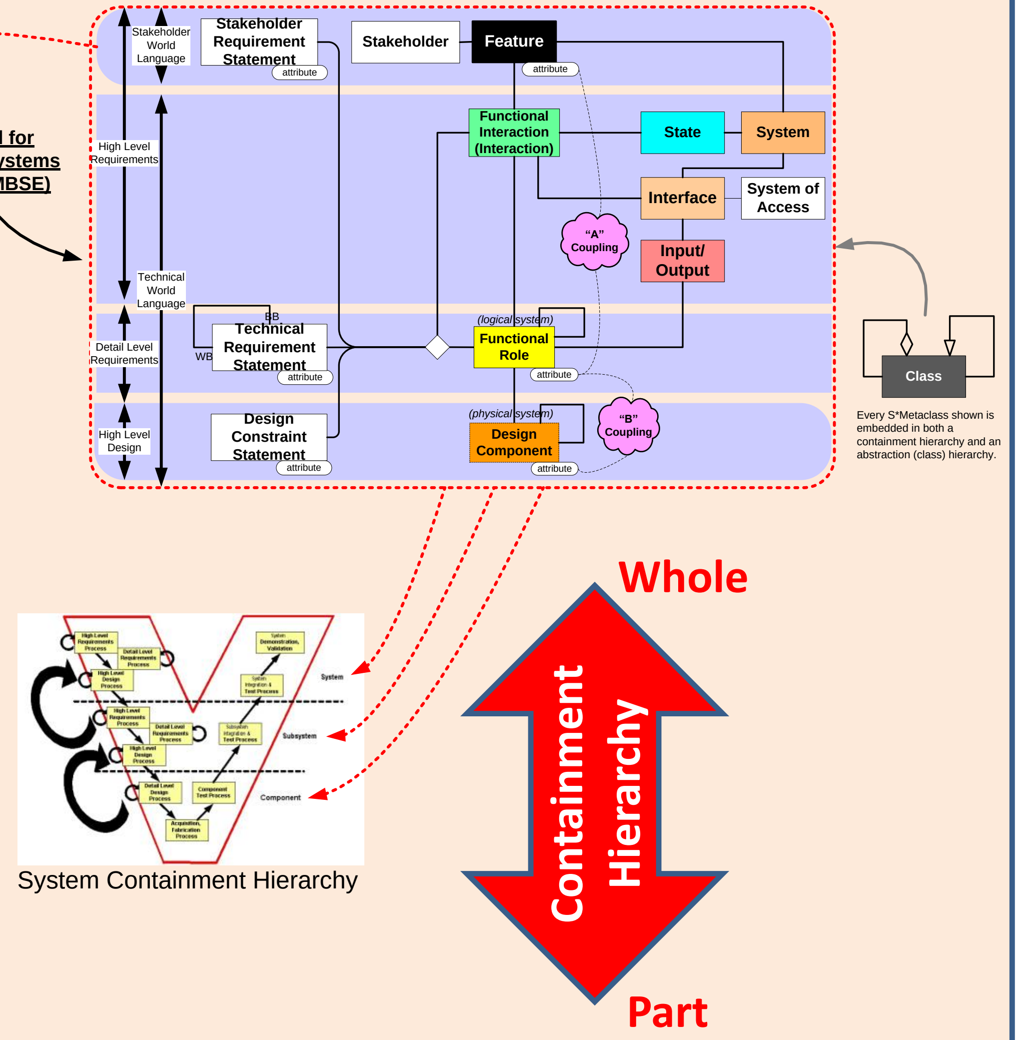
		Units	Walk-Behind	Walk-Behind	Walk-Behind	Riding	Riding	Riding Mower	Autonomous
			Push Mower	Mower	Self-Propelled	Rider	Tractor	Tractor	Autonomous
			Push Mower	Self-Propelled	Wide Cut	Rider	Lawn	Garden	Auto Mower
	Model Number		M3	M5	M11	M17	M19	M23	M100
	Market Segment		Sm Resident	Med Resident	Med Resident	Lg Resident	Lg Resident	Home Garden	High End Suburban
Power	Engine Manufacturer		B&S	B&S	Tecumseh	Tecumseh	Kohler	Kohler	Elektroset
	Horsepower	HP	5	6.5	13	16	18.5	22	0.5
Production	Cutting Width	Inches	17	19	36	36	42	48	16
	Maximum Mowing Speed	MPH	3	3	4	8	10	12	2.5
	Maximum Mowing Productivity	Acres/Hr			1.6				
	Turning Radius	Inches	0	0	0	0	126	165	0
	Fuel Tank Capacity	Hours	1.5	1.7	2.5	2.8	3.2	3.5	2
	Towing Feature						x	x	
	Electric Starter Feature				x	x	x	x	
	Basic Mowing Feature Group		x	x	x	x	x	x	x
Mower	No. of Anti-Scalping Rollers		0	0	1	2	4	6	0
	Cutting Height Minimum	Inches	1	1.5	1.5	1.5	1	1.5	1.2
	Cutting Height Maximum	Inches	4	5	5	6	8	10	3.8
	Operator Riding Feature					x	x	x	
	Grass Bagging Feature		Optional	Optional	Optional	Optional	Optional	Optional	
	Mulching Feature		Standard	Factory Installed	Dealer Installed				
	Aerator Feature					Optional	Optional	Optional	
	Autonomous Mowing Feature								x
	Dethatching Feature					Optional	Optional	Optional	
Physical	Wheel Base	Inches	18	20	22	40	48	52	16
	Overall Length	Inches	18	20	23	58	56	68	28.3
	Overall Height	Inches	40	42	42	30	32	36	10.3
	Width	Inches	18	20	22	40	48	52	23.6
	Weight	Pounds	120	160	300	680	705	1020	15.6
	Self-Propelled Mowing Feature			x	x	x	x	x	x
	Automatic TransmFeature							x	
Financials	Retail Price	Dollars	360	460	1800	3300	6100	9990	1799
	Manufacturer Cost	Dollars	120	140	550	950	1800	3500	310
Maintenance	Warranty	Months	12	12	18	24	24	24	12
	Product Service Life	Hours	500	500	600	1100	1350	1500	300
	Time Between Service	Hours	100	100	150	200	200	250	100
Safety	Spark Arrest Feature		x	x	x	x	x	x	

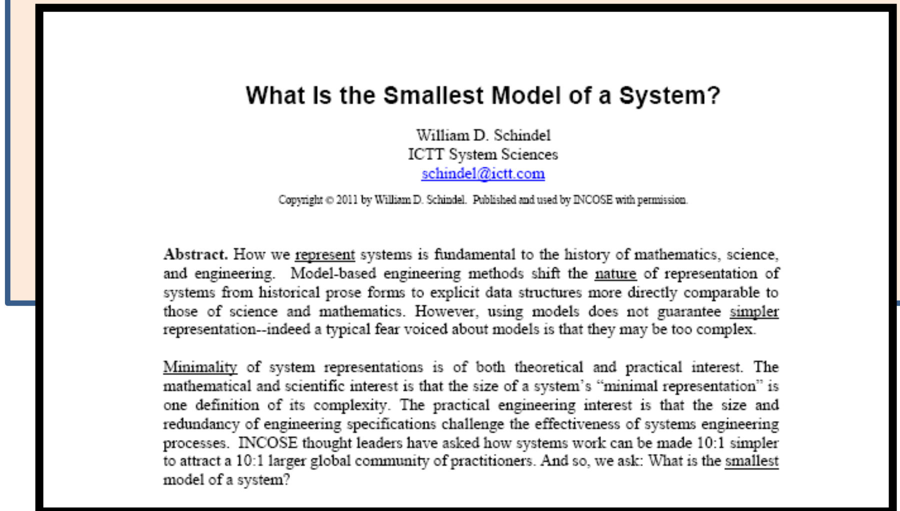




Two entirely different hierarchies are involved:







What Is the Smallest Model of a System?

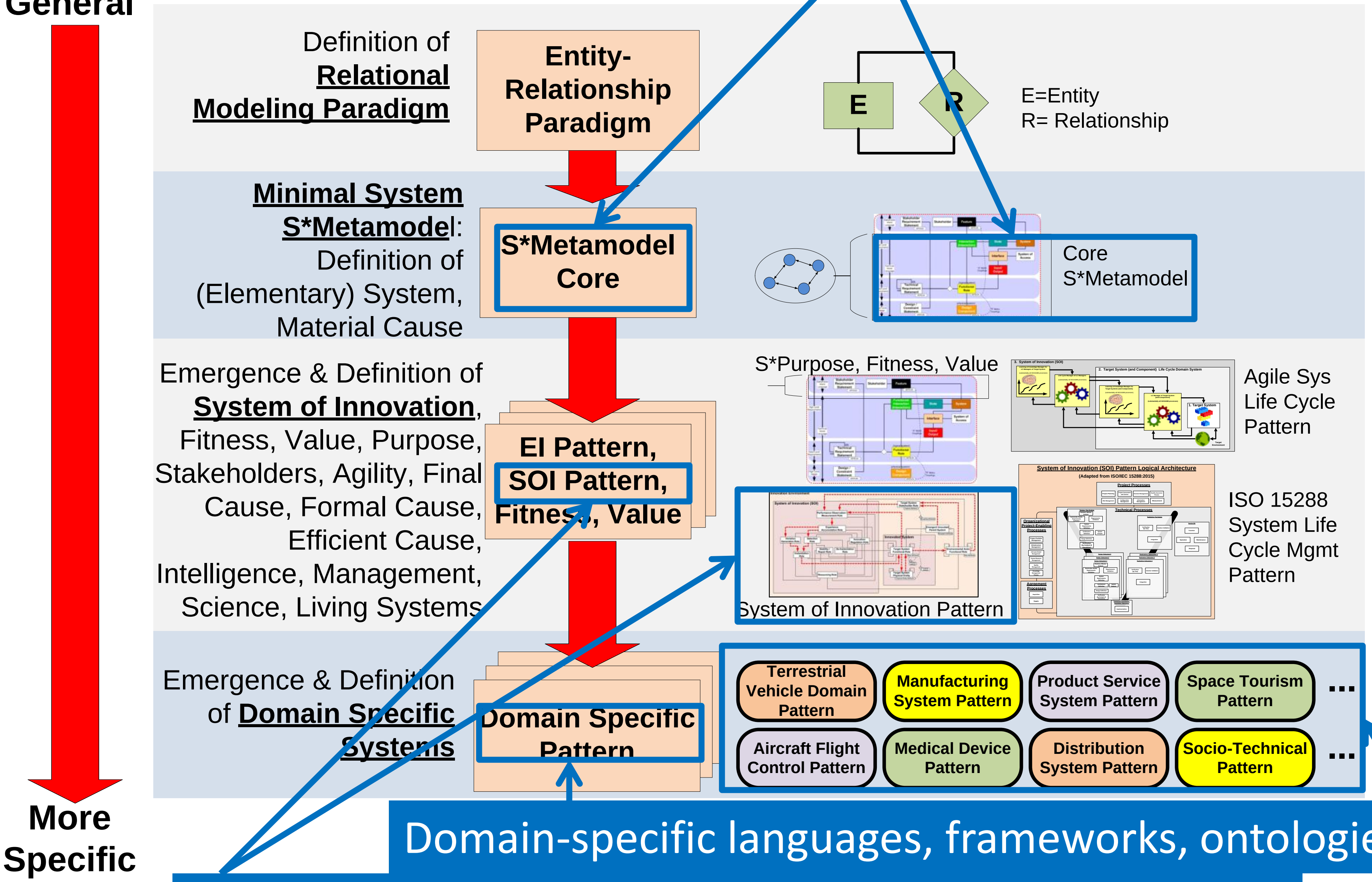
William D. Schindel
ICTT System Sciences
schindel@ictt.com

Abstract. How we represent systems is fundamental to the history of mathematics, science, and engineering. Model-based engineering methods shift the nature of representation of systems from historical prose forms to explicit data structures more directly comparable to those of science and mathematics. However, using models does not guarantee simpler representation--indeed a typical fear voiced about models is that they may be too complex.

Minimality of system representations is of both theoretical and practical interest. The mathematical and scientific interest is that the size of a system's "minimal representation" is one definition of its complexity. The practical engineering interest is that the size and redundancy of engineering specifications challenge the effectiveness of systems engineering processes. INCOSE thought leaders have asked how systems work can be made 10:1 simpler to attract a 10:1 larger global community of practitioners. And so, we ask: What is the smallest model of a system?

Universal systems nomenclature, domain-independent.

Emergence of Patterns from Patterns: S*Pattern Class Hierarchy



More General

More Specific

Definition of **Relational Modeling Paradigm**

Entity-Relationship Paradigm

E=Entity
R= Relationship

Minimal System S*Metamodel: Definition of (Elementary) System, Material Cause

S*Metamodel Core

Core S*Metamodel

Emergence & Definition of **System of Innovation**, Fitness, Value, Purpose, Stakeholders, Agility, Final Cause, Formal Cause, Efficient Cause, Intelligence, Management, Science, Living Systems

EI Pattern,
SOI Pattern,
Fitness, Value

S*Purpose, Fitness, Value

Agile Sys Life Cycle Pattern

System of Innovation Pattern

ISO 15288 System Life Cycle Mgmt Pattern

Emergence & Definition of **Domain Specific Systems**

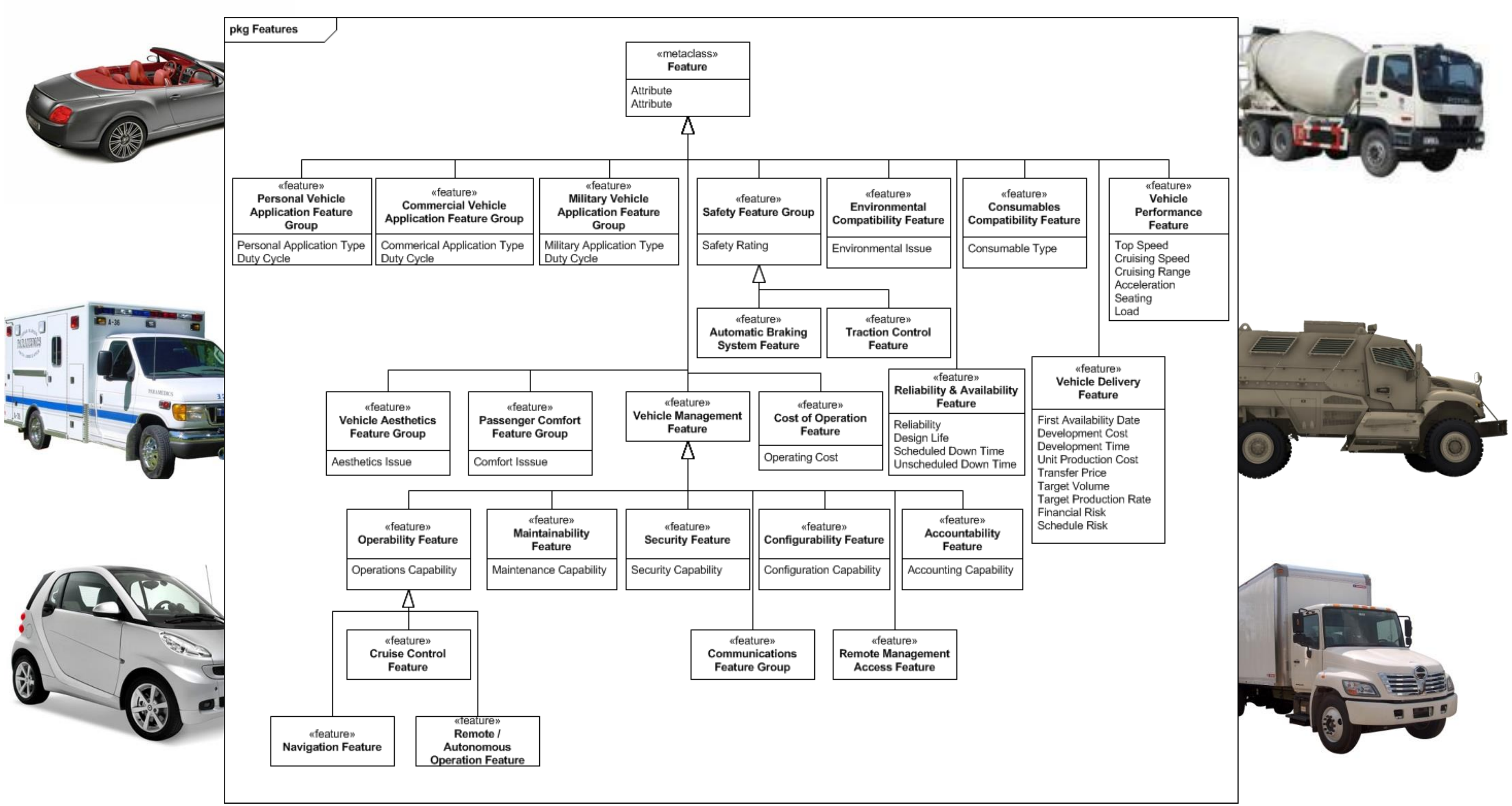
Domain Specific Pattern

Terrestrial Vehicle Domain Pattern	**Manufacturing System Pattern**	**Product Service System Pattern**	**Space Tourism Pattern**	**…**
Aircraft Flight Control Pattern	**Medical Device Pattern**	**Distribution System Pattern**	**Socio-Technical Pattern**	**…**

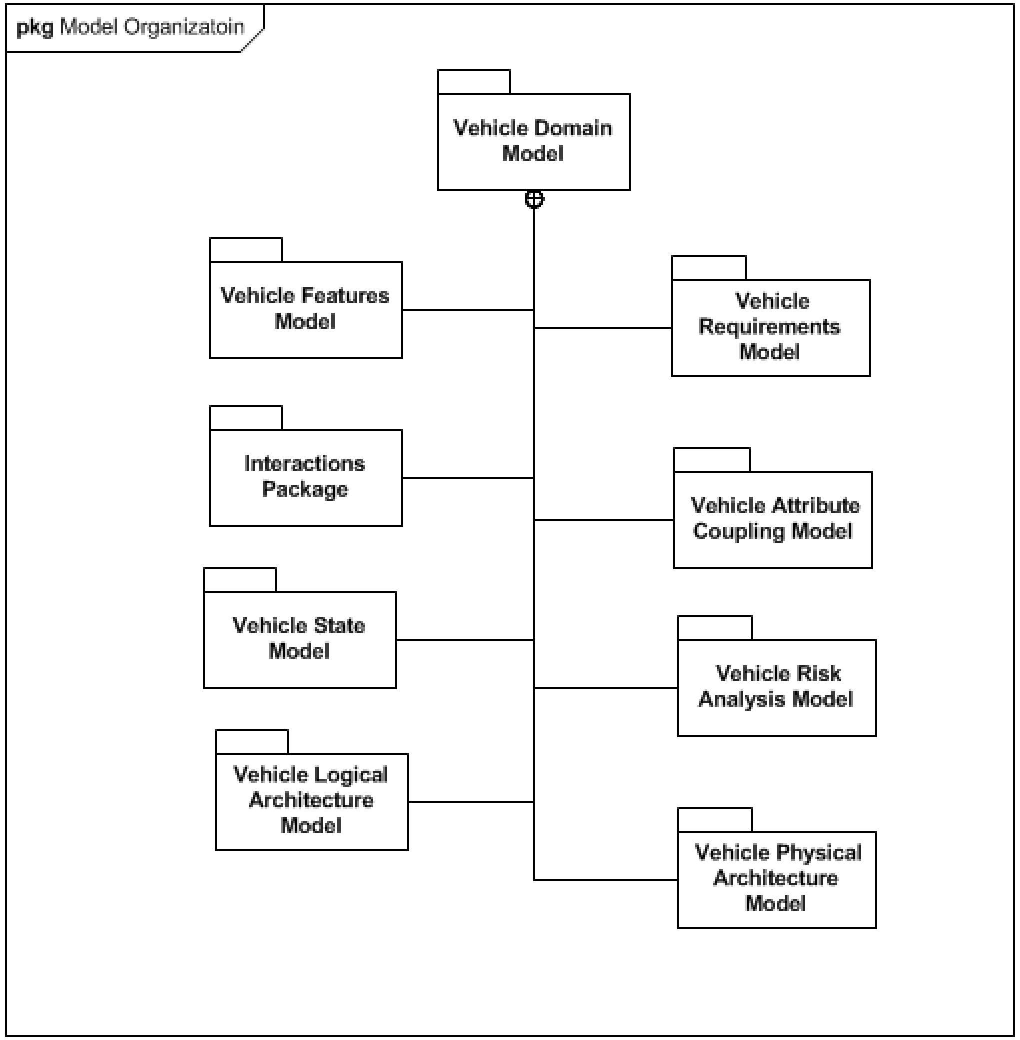
Domain-specific languages, frameworks, ontologies.

Generator of “new systems”; also maintainer, destroyer

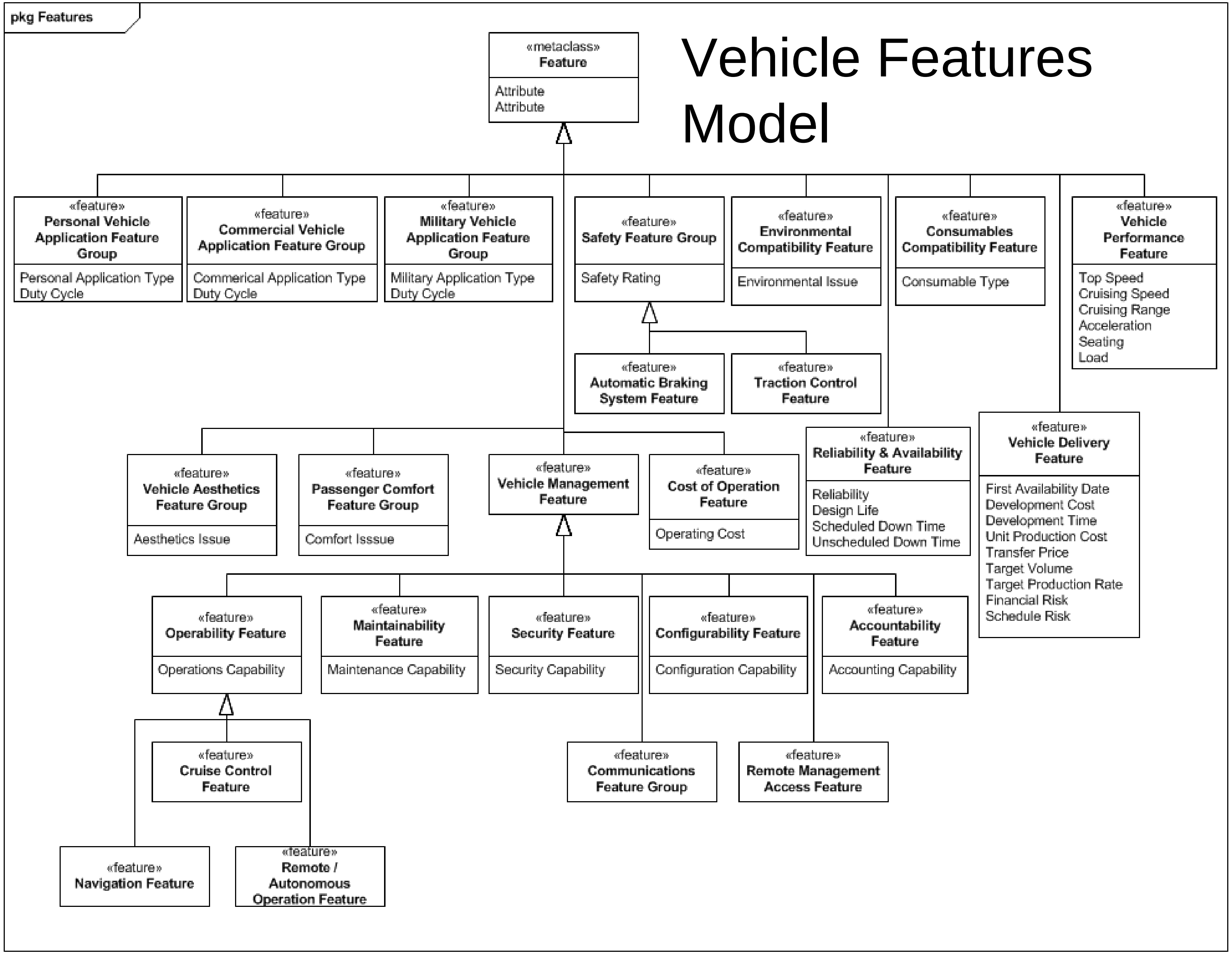
A vehicle pattern in SysML



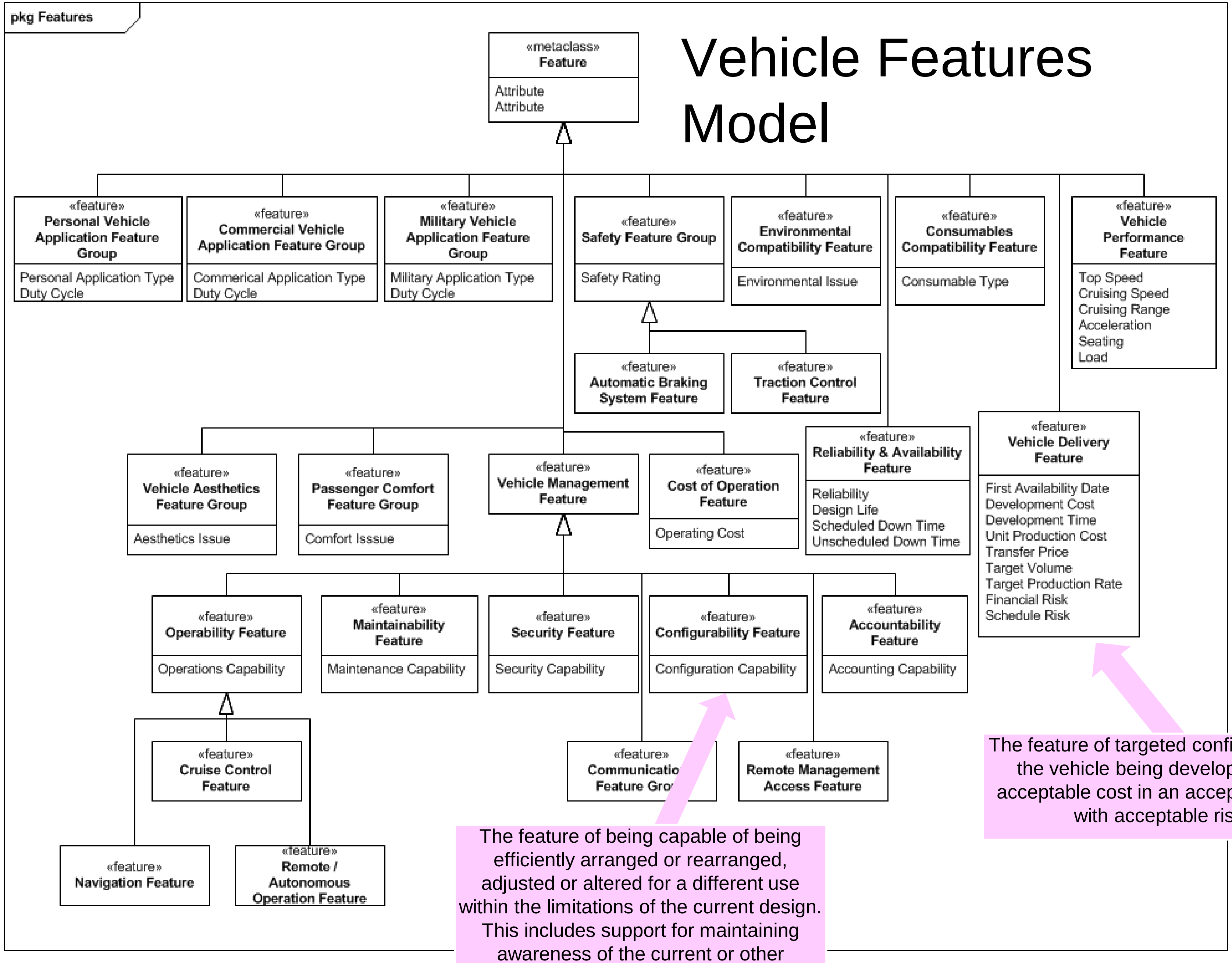
Vehicle Pattern:
Model Organization (Packages)



Vehicle Features Model



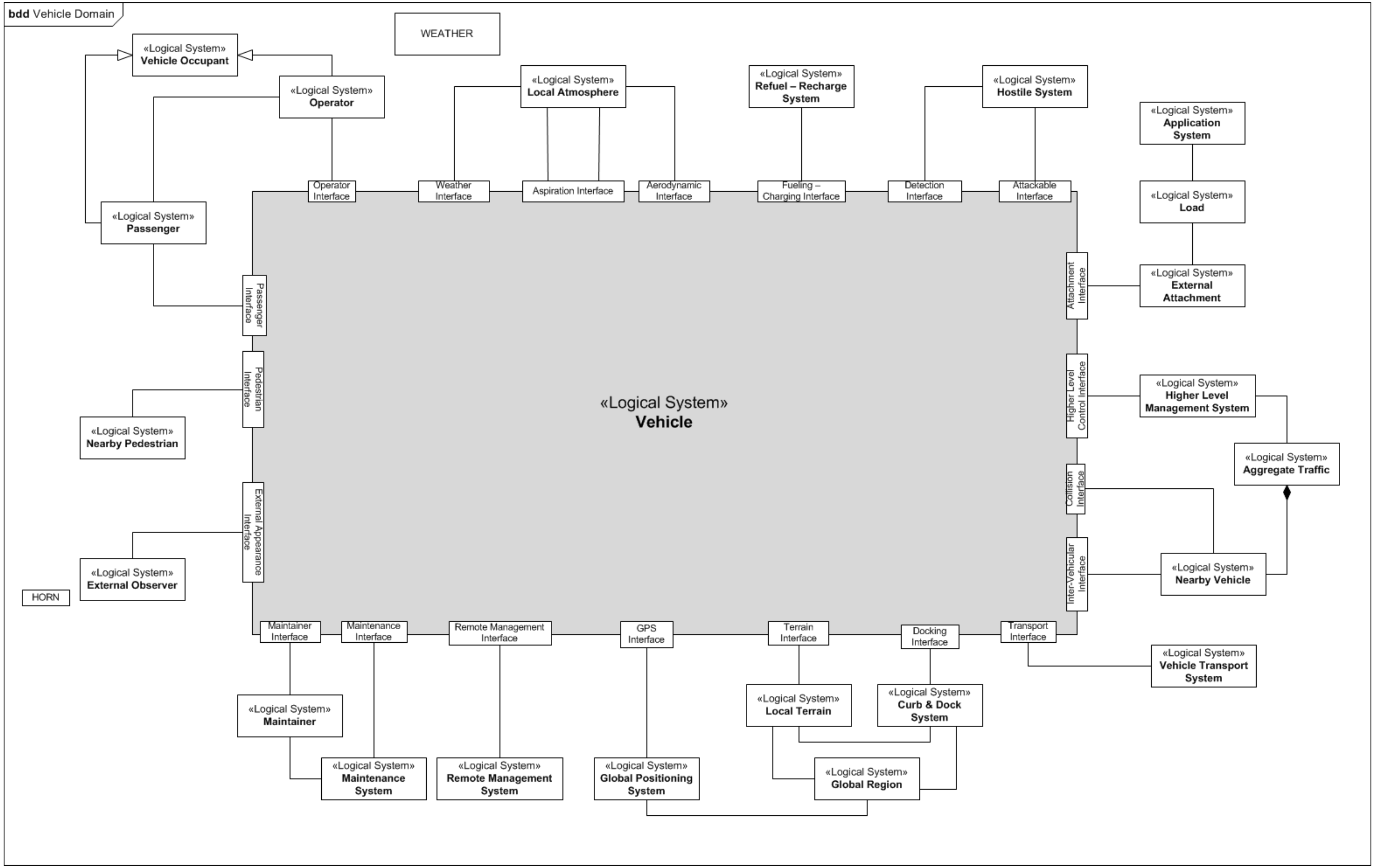
Vehicle Features Model



The feature of targeted configurations of the vehicle being developed at an acceptable cost in an acceptable time, with acceptable risk.

The feature of being capable of being efficiently arranged or rearranged, adjusted or altered for a different use within the limitations of the current design. This includes support for maintaining awareness of the current or other configurations of the system.

Vehicle Domain Model



bdd Vehicle Domain

WEATHER

«Logical System» **Vehicle Occupant**

«Logical System» **Operator**

«Logical System» **Passenger**

«Logical System» **Local Atmosphere**

«Logical System» **Refuel – Recharge System**

«Logical System» **Hostile System**

«Logical System» **Application System**

«Logical System» **Load**

«Logical System» **External Attachment**

Operator Interface

Weather Interface

Aspiration Interface

Aerodynamic Interface

Fueling – Charging Interface

Detection Interface

Attackable Interface

Passenger Interface

Pedestrian Interface

External Appearance Interface

Attachment Interface

Higher Level Control Interface

Collision Interface

Inter-Vehicular Interface

«Logical System» **Vehicle**

«Logical System» **Nearby Pedestrian**

«Logical System» **External Observer**

HORN

«Logical System» **Higher Level Management System**

«Logical System» **Aggregate Traffic**

«Logical System» **Nearby Vehicle**

Maintainer Interface

Maintenance Interface

Remote Management Interface

GPS Interface

Terrain Interface

Docking Interface

Transport Interface

«Logical System» **Vehicle Transport System**

«Logical System» **Maintainer**

«Logical System» **Local Terrain**

«Logical System» **Curb & Dock System**

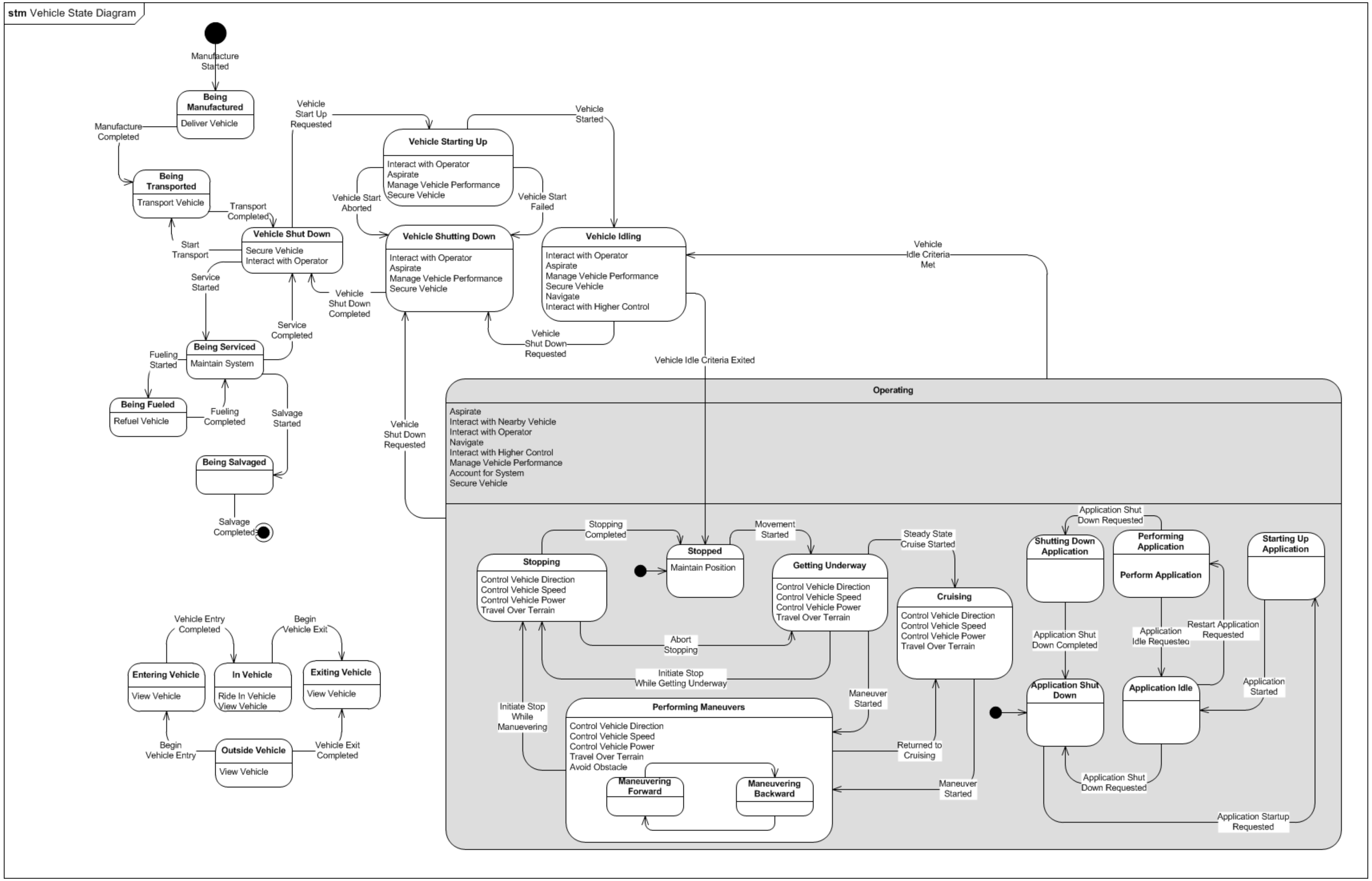
«Logical System» **Maintenance System**

«Logical System» **Remote Management System**

«Logical System» **Global Positioning System**

«Logical System» **Global Region**

Vehicle State Model

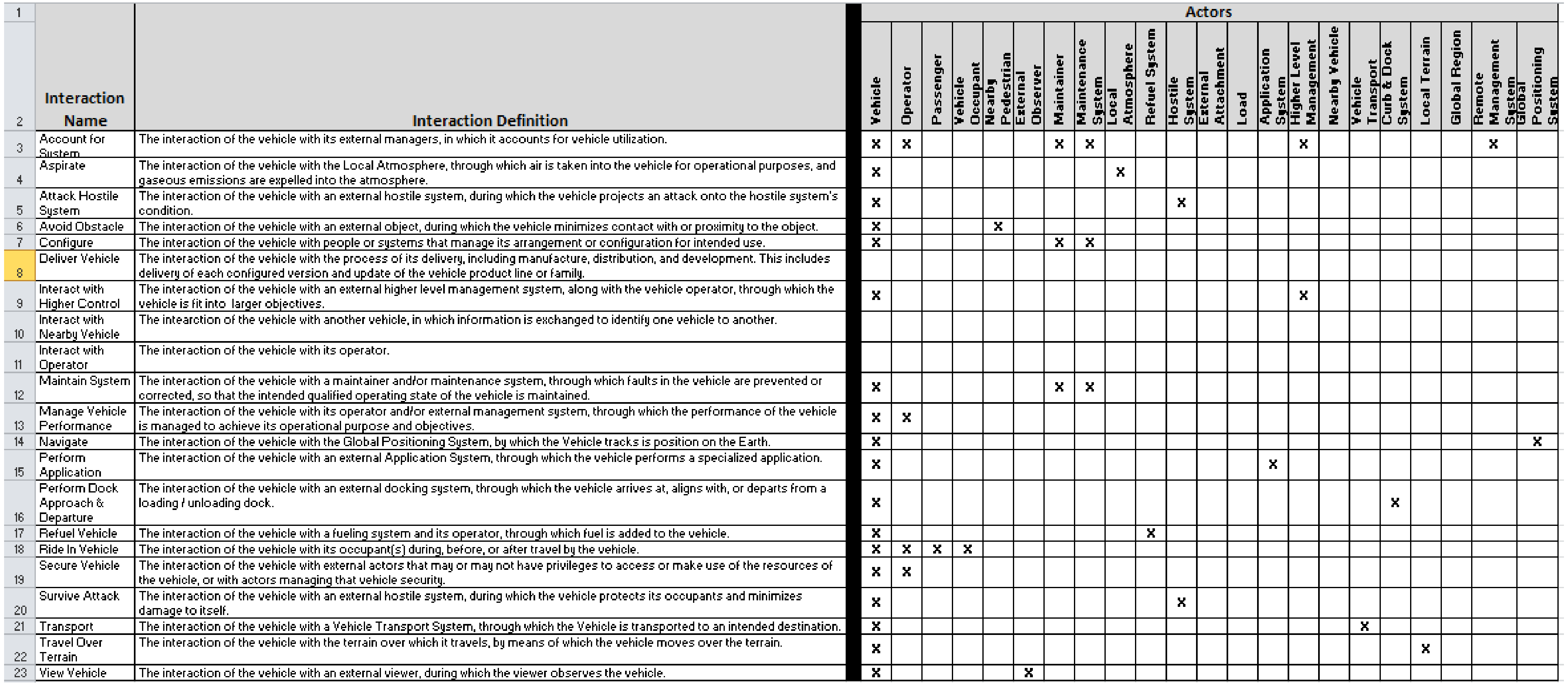


Vehicle Interaction Model

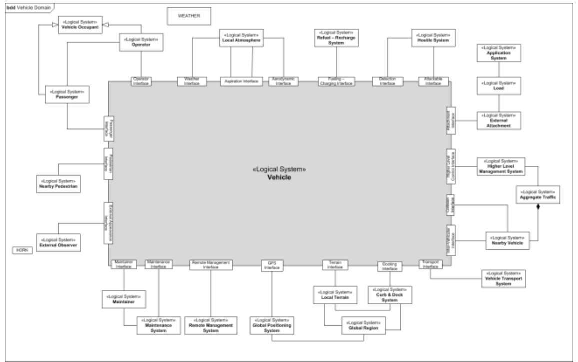
pkg Interactions

- «Interaction» **Travel Over Terrain**
- «Interaction» **Avoid Obstacle**
- «Interaction» **Ride in Vehicle**
- «Interaction» **Interact with Nearby Vehicle**
- «Interaction» **Perform Dock Approach & Departure**
- «Interaction» **Refuel Vehicle**
- **«Interaction» Aspirate**
- «Interaction» **Deliver Vehicle**
- «Interaction» **Transport Vehicle**
- «Interaction» **Interact with Operator**
- «Interaction» **Navigate**
- «Interaction» **Interact with Higher Control**
- «Interaction» **View Vehicle**
- «Interaction» **Manage Vehicle Performance**
- «Interaction» **Configure Vehicle**
- «Interaction» **Maintain System**
- «Interaction» **Account for System**
- «Interaction» **Secure Vehicle**
- «Interaction» **Attack Hostile System**
- «Interaction» **Survive Attack**
- «Interaction» **Perform Application**

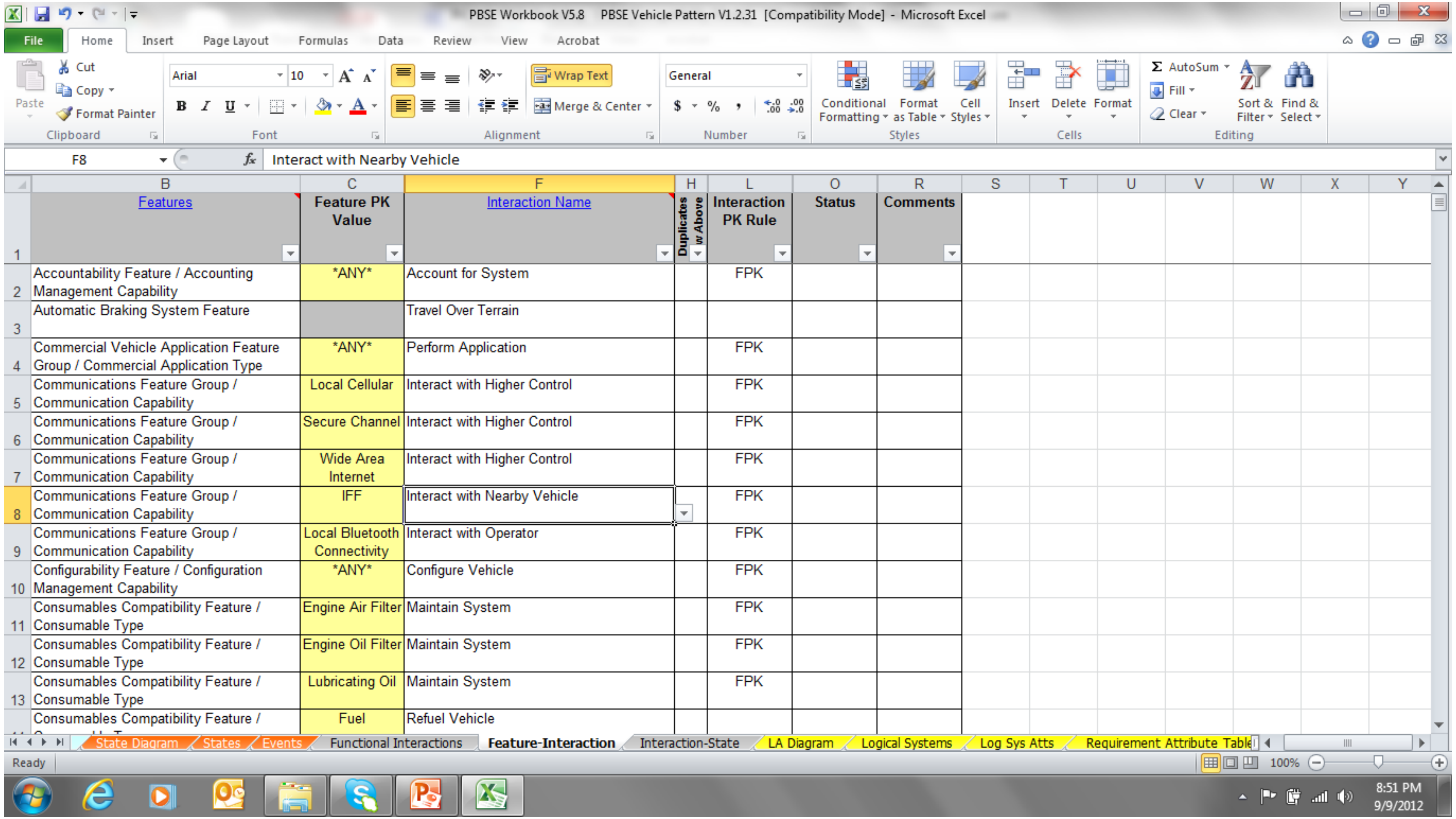
Vehicle Interactions:
Which Actors Participate in Interaction?



1			Actors																					
2	Interaction Name	Interaction Definition	Vehicle	Operator	Passenger	Vehicle Occupant	Nearby Pedestrian	External Observer	Maintainer	Maintenance System	Local Atmosphere	Refuel System	Hostile System	External Attachment	Load	Application System	Higher Level Management	Nearby Vehicle	Vehicle Transport	Curb & Dock System	Local Terrain	Global Region	Remote Management System	Global Positioning System
3	Account for System	The interaction of the vehicle with its external managers, in which it accounts for vehicle utilization.	x	x					x	x							x						x	
4	Aspirate	The interaction of the vehicle with the Local Atmosphere, through which air is taken into the vehicle for operational purposes, and gaseous emissions are expelled into the atmosphere.	x								x													
5	Attack Hostile System	The interaction of the vehicle with an external hostile system, during which the vehicle projects an attack onto the hostile system's condition.	x										x											
6	Avoid Obstacle	The interaction of the vehicle with an external object, during which the vehicle minimizes contact with or proximity to the object.	x				x																	
7	Configure	The interaction of the vehicle with people or systems that manage its arrangement or configuration for intended use.	x						x	x														
8	Deliver Vehicle	The interaction of the vehicle with the process of its delivery, including manufacture, distribution, and development. This includes delivery of each configured version and update of the vehicle product line or family.																						
9	Interact with Higher Control	The interaction of the vehicle with an external higher level management system, along with the vehicle operator, through which the vehicle is fit into larger objectives.	x														x							
10	Interact with Nearby Vehicle	The intearction of the vehicle with another vehicle, in which information is exchanged to identify one vehicle to another.																						
11	Interact with Operator	The interaction of the vehicle with its operator.																						
12	Maintain System	The interaction of the vehicle with a maintainer and/or maintenance system, through which faults in the vehicle are prevented or corrected, so that the intended qualified operating state of the vehicle is maintained.	x						x	x														
13	Manage Vehicle Performance	The interaction of the vehicle with its operator and/or external management system, through which the performance of the vehicle is managed to achieve its operational purpose and objectives.	x	x																				
14	Navigate	The interaction of the vehicle with the Global Positioning System, by which the Vehicle tracks is position on the Earth.	x																					x
15	Perform Application	The interaction of the vehicle with an external Application System, through which the vehicle performs a specialized application.	x													x								
16	Perform Dock Approach & Departure	The interaction of the vehicle with an external docking system, through which the vehicle arrives at, aligns with, or departs from a loading / unloading dock.	x																	x				
17	Refuel Vehicle	The interaction of the vehicle with a fueling system and its operator, through which fuel is added to the vehicle.	x									x												
18	Ride In Vehicle	The interaction of the vehicle with its occupant(s) during, before, or after travel by the vehicle.	x	x	x	x																		
19	Secure Vehicle	The interaction of the vehicle with external actors that may or may not have privileges to access or make use of the resources of the vehicle, or with actors managing that vehicle security.	x	x																				
20	Survive Attack	The interaction of the vehicle with an external hostile system, during which the vehicle protects its occupants and minimizes damage to itself.	x										x											
21	Transport	The interaction of the vehicle with a Vehicle Transport System, through which the Vehicle is transported to an intended destination.	x																x					
22	Travel Over Terrain	The interaction of the vehicle with the terrain over which it travels, by means of which the vehicle moves over the terrain.	x																		x			
23	View Vehicle	The interaction of the vehicle with an external viewer, during which the viewer observes the vehicle.	x					x																



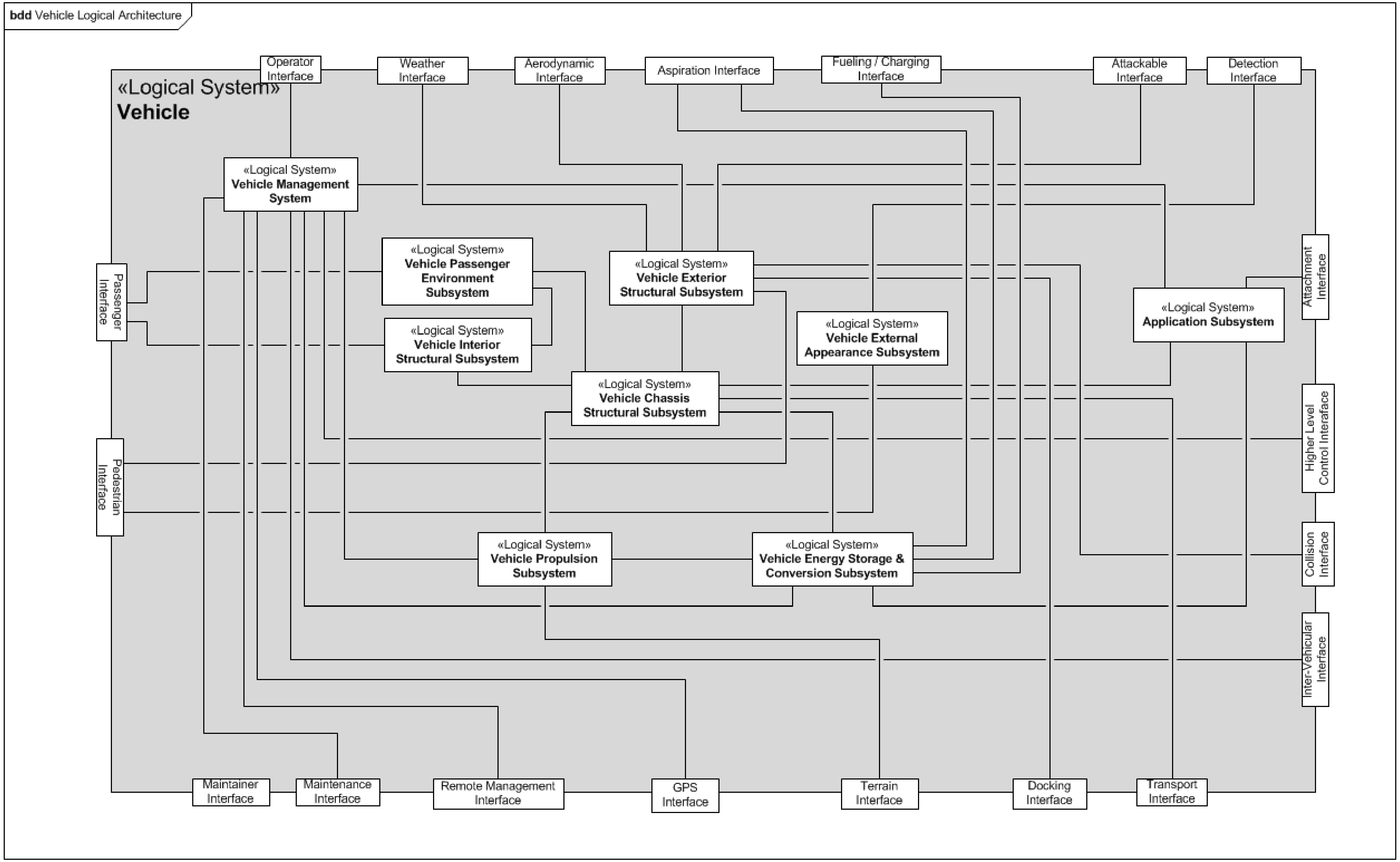
Vehicle Feature-Interaction Associations



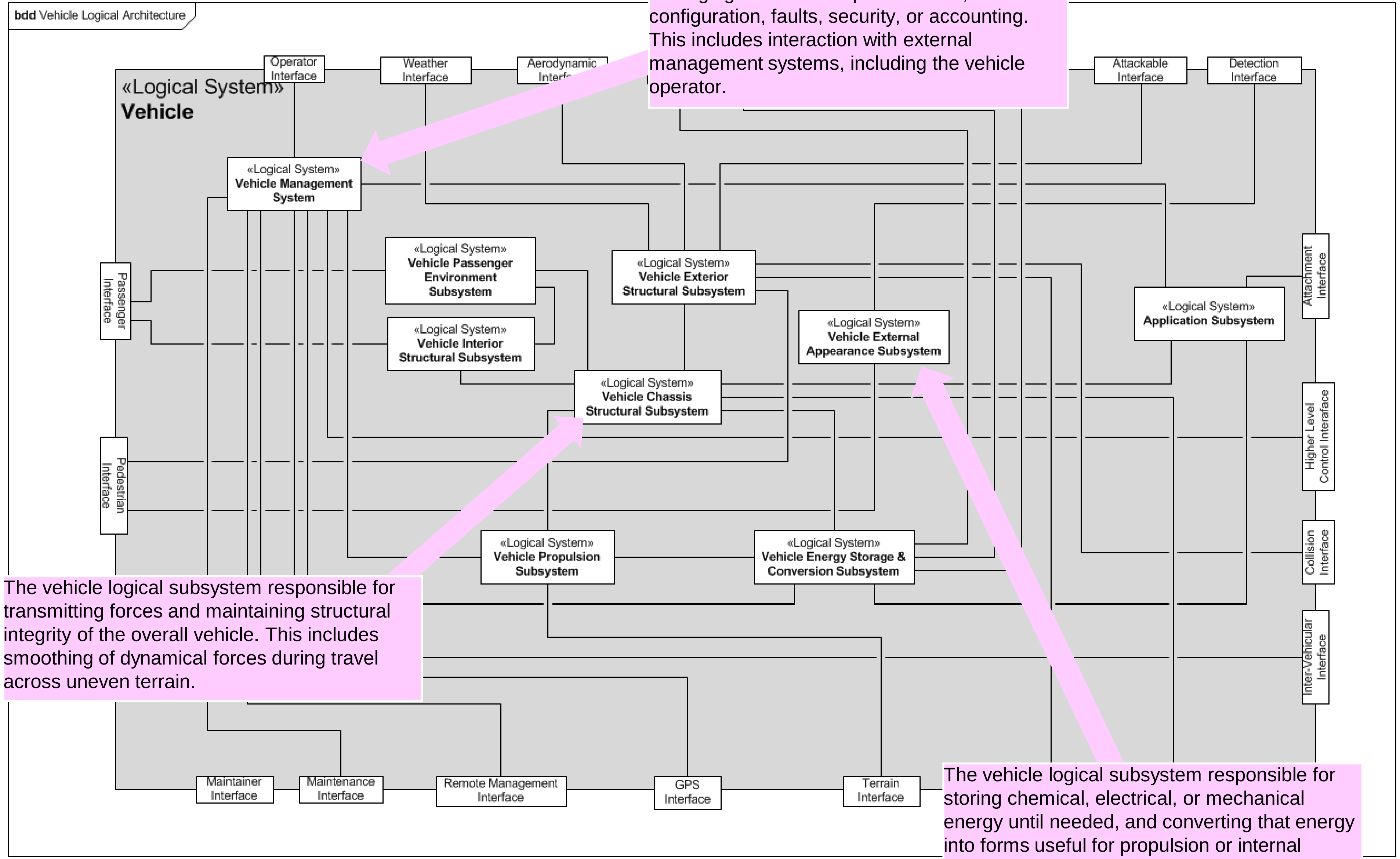
F8 Interact with Nearby Vehicle

	B	C	F	H	L	O	R
1	Features	Feature PK Value	Interaction Name	Duplicates w Above	Interaction PK Rule	Status	Comments
2	Accountability Feature / Accounting Management Capability	*ANY*	Account for System		FPK		
3	Automatic Braking System Feature		Travel Over Terrain				
4	Commercial Vehicle Application Feature Group / Commercial Application Type	*ANY*	Perform Application		FPK		
5	Communications Feature Group / Communication Capability	Local Cellular	Interact with Higher Control		FPK		
6	Communications Feature Group / Communication Capability	Secure Channel	Interact with Higher Control		FPK		
7	Communications Feature Group / Communication Capability	Wide Area Internet	Interact with Higher Control		FPK		
8	Communications Feature Group / Communication Capability	IFF	Interact with Nearby Vehicle		FPK		
9	Communications Feature Group / Communication Capability	Local Bluetooth Connectivity	Interact with Operator		FPK		
10	Configurability Feature / Configuration Management Capability	*ANY*	Configure Vehicle		FPK		
11	Consumables Compatibility Feature / Consumable Type	Engine Air Filter	Maintain System		FPK		
12	Consumables Compatibility Feature / Consumable Type	Engine Oil Filter	Maintain System		FPK		
13	Consumables Compatibility Feature / Consumable Type	Lubricating Oil	Maintain System		FPK		
	Consumables Compatibility Feature /	Fuel	Refuel Vehicle				

Logical Architecture Model



Logical Architecture Model

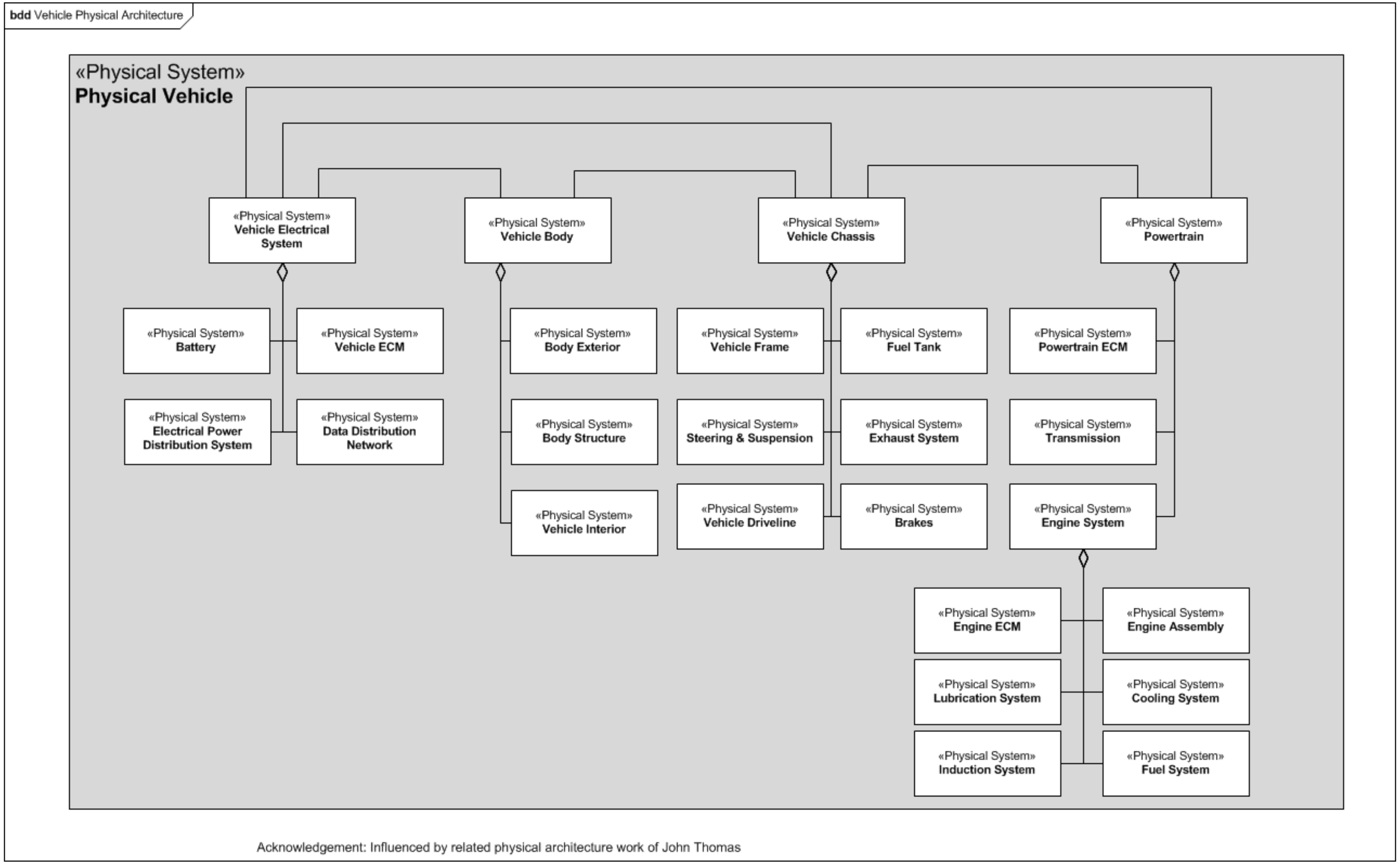


The vehicle logical subsystem responsible for managing vehicle-level performance, configuration, faults, security, or accounting. This includes interaction with external management systems, including the vehicle operator.

The vehicle logical subsystem responsible for transmitting forces and maintaining structural integrity of the overall vehicle. This includes smoothing of dynamical forces during travel across uneven terrain.

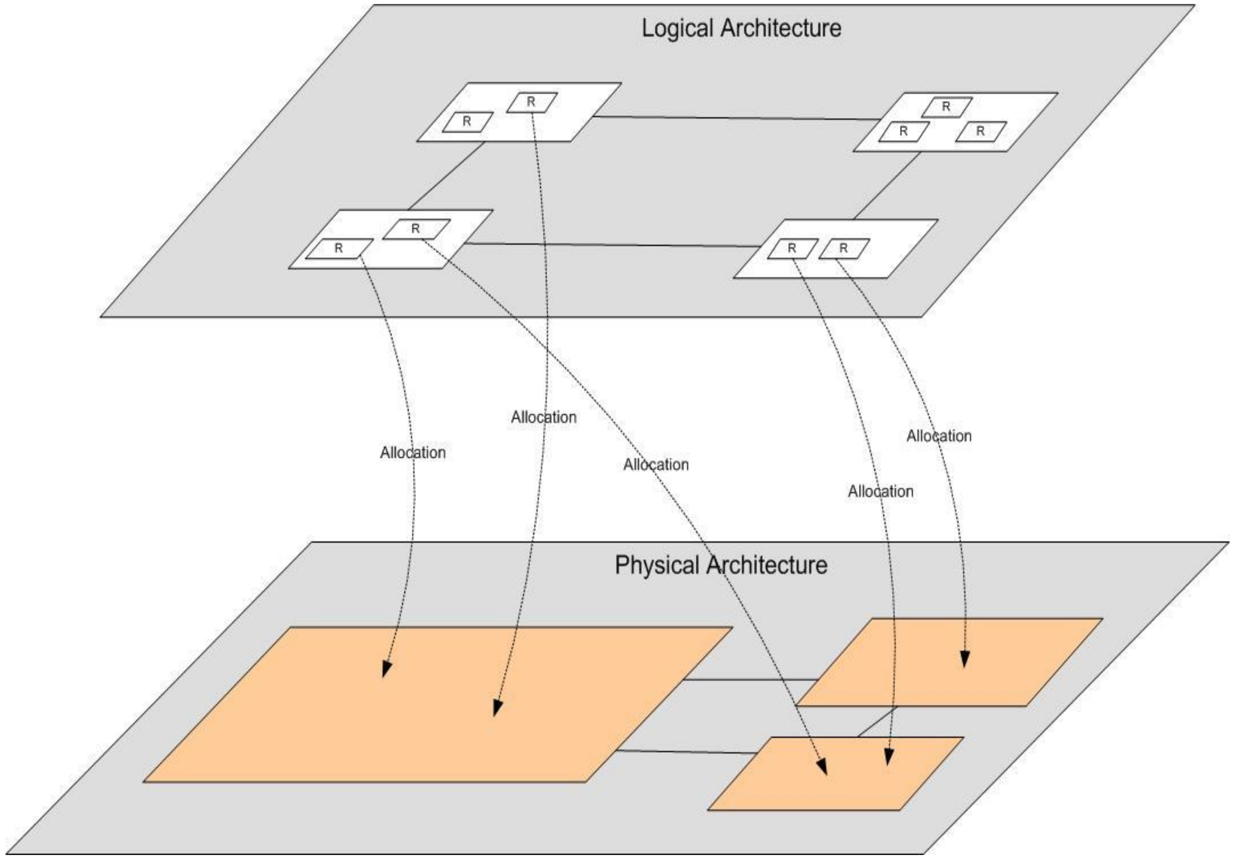
The vehicle logical subsystem responsible for storing chemical, electrical, or mechanical energy until needed, and converting that energy into forms useful for propulsion or internal consumption.

Physical Architecture Model



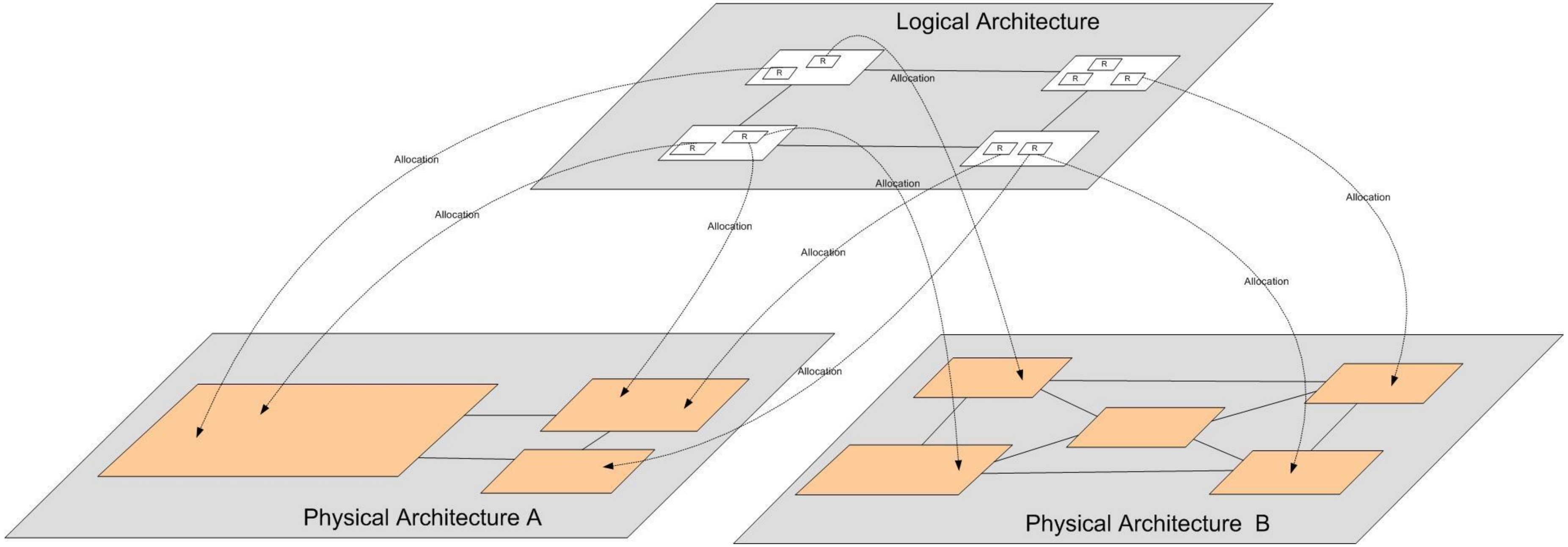
Acknowledgement: Influenced by related physical architecture work of John Thomas

Allocation of Logical Roles to Physical Architecture

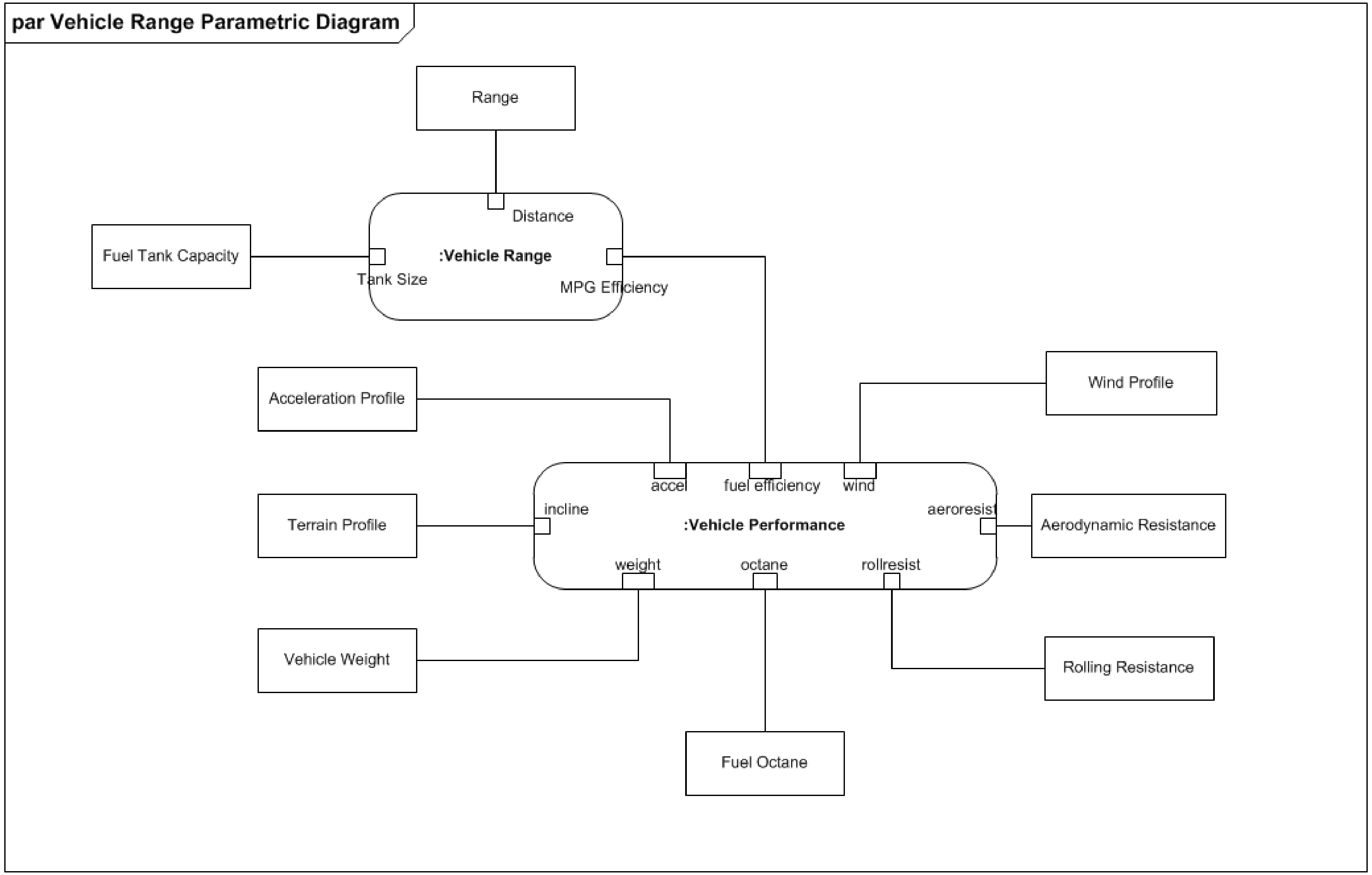


Allocation of Logical Roles to Physical Architecture

- Same Logical Architecture covers many Physical Architectures:



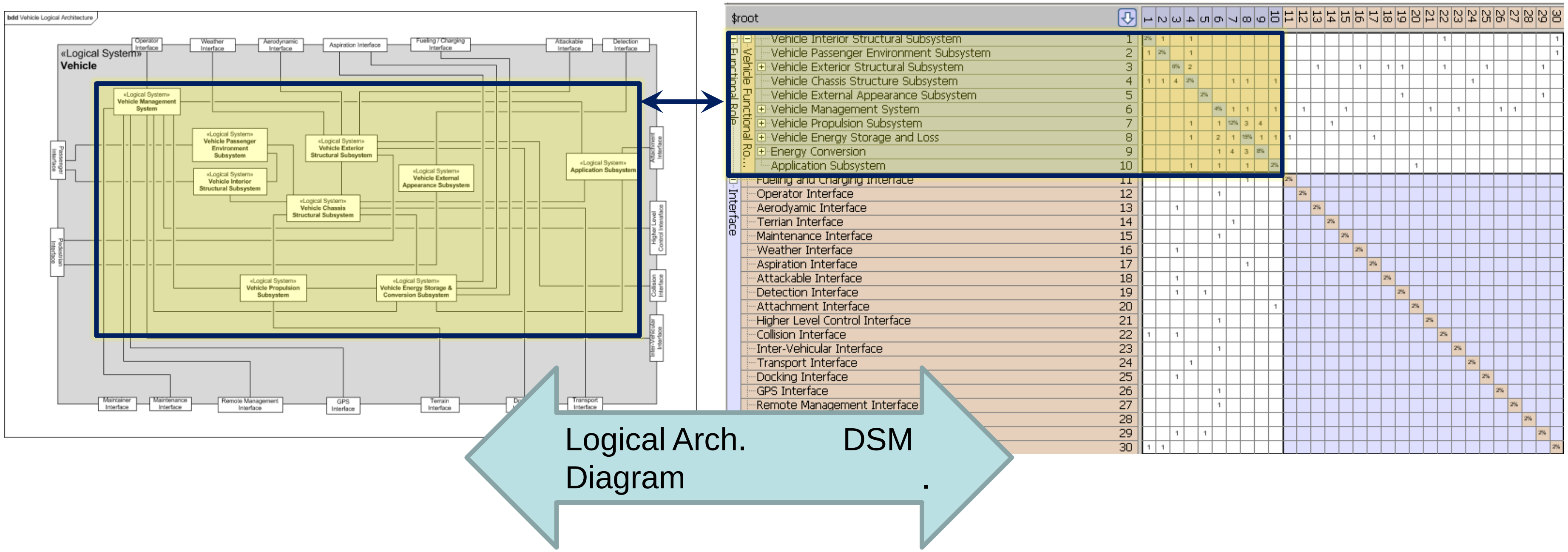
Attribute Coupling Model



Logical Architecture Views

Block Diagram and Design Structure Matrix (DSM)

- The structure shown in these architectural diagrams can also be expressed in matrix form
  - These matrices are known as: N^2 matrices, Adjacency Matrices and Design or Dependency Structure Matrices (DSMs)
  - N^2 because their column and row headings are identical, with the matrix cells showing “marks” indicating relationships between components.



1 Vehicle Interior Structural Subsystem
2 Vehicle Passenger Environment Subsystem
3 Vehicle Exterior Structural Subsystem
4 Vehicle Chassis Structure Subsystem
5 Vehicle External Appearance Subsystem
6 Vehicle Management System
7 Vehicle Propulsion Subsystem
8 Vehicle Energy Storage and Loss
9 Energy Conversion
10 Application Subsystem
11 Fueling and Charging Interface
12 Operator Interface
13 Aerodyamic Interface
14 Terrian Interface
15 Maintenance Interface
16 Weather Interface
17 Aspiration Interface
18 Attackable Interface
19 Detection Interface
20 Attachment Interface
21 Higher Level Control Interface
22 Collision Interface
23 Inter-Vehicular Interface
24 Transport Interface
25 Docking Interface
26 GPS Interface
27 Remote Management Interface
28
29
30

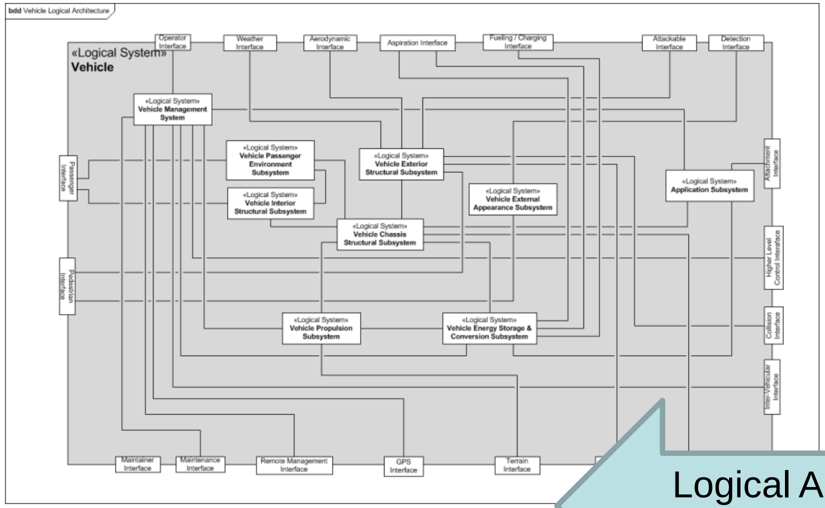
Logical Arch. Diagram

DSM .

Logical Architecture Views

Block Diagram and Design Structure Matrix (DSM)

- In the case of Logical Architecture:
  - The blocks in the LA diagram become rows and columns of the DSM
  - The connection lines in the LA diagram become marks in the DSM
- Both views are visualizations of the same information:
  - However the functionality has been partitioned into interacting subsets – Vehicle Functional Roles and Interfaces in this case.



Logical Arch. Diagram

DSM

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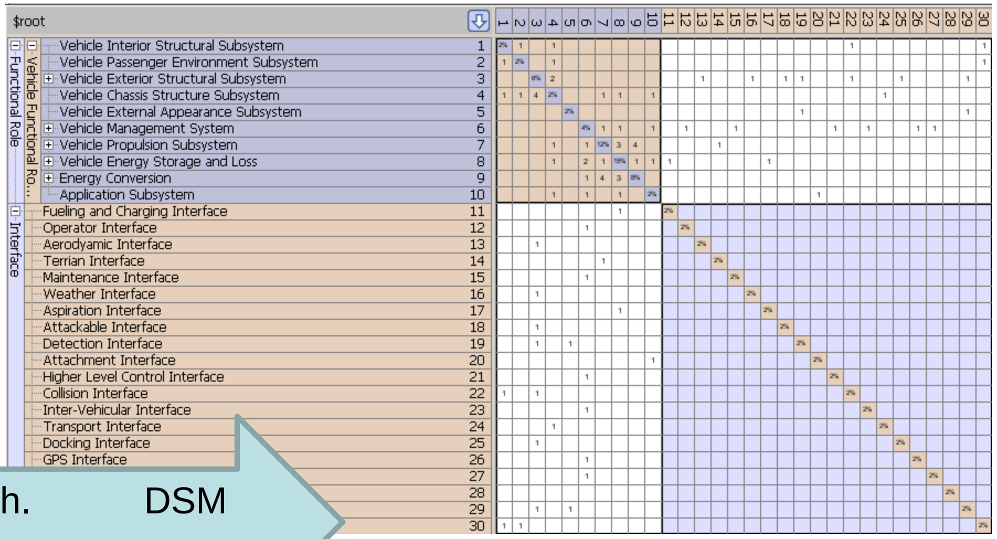
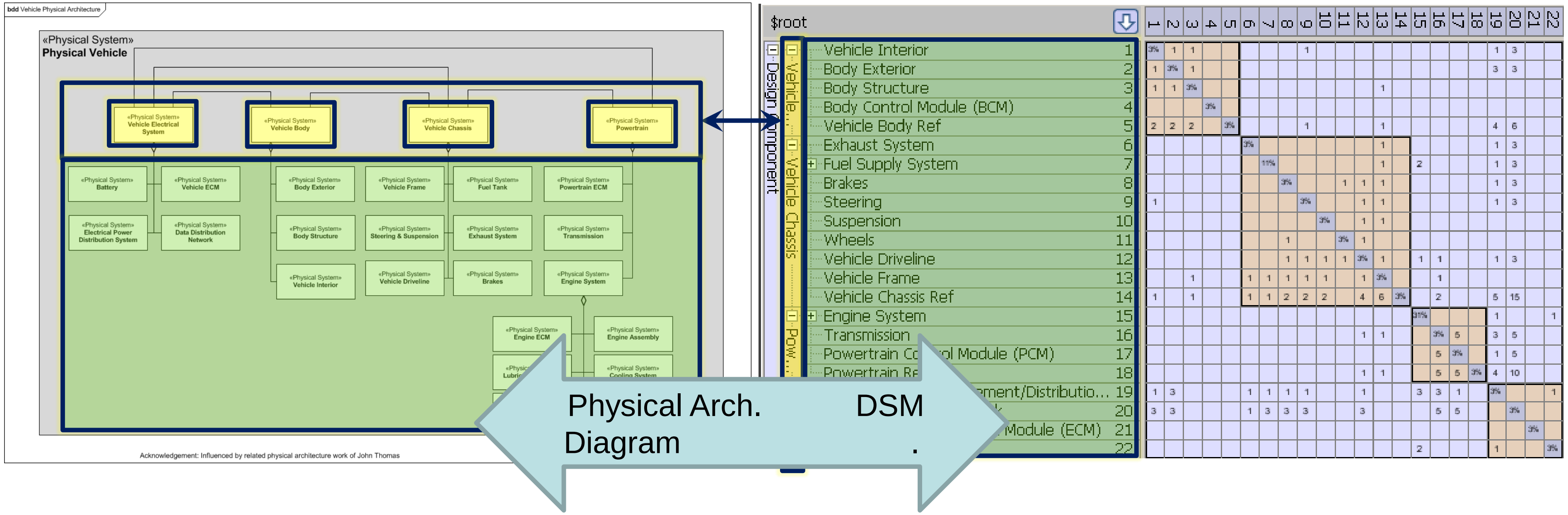


$root				1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
Functional Role	Vehicle Functional Ro...	Vehicle Interior Structural Subsystem	1	2%	1		1																		1								1
		Vehicle Passenger Environment Subsystem	2	1	2%		1																										1
		Vehicle Exterior Structural Subsystem	3			6%	2									1			1		1	1			1			1				1	
		Vehicle Chassis Structure Subsystem	4	1	1	4	2%			1	1		1														1						
		Vehicle External Appearance Subsystem	5					2%														1										1	
		Vehicle Management System	6						4%	1	1		1		1			1						1		1			1	1			
		Vehicle Propulsion Subsystem	7				1		1	12%	3	4					1																
		Vehicle Energy Storage and Loss	8				1		2	1	15%	1	1	1						1													
		Energy Conversion	9						1	4	3	8%																					
		Application Subsystem	10				1		1		1		2%										1										
Interface		Fueling and Charging Interface	11								1			2%																			
		Operator Interface	12						1						2%																		
		Aerodyamic Interface	13			1										2%																	
		Terrian Interface	14							1							2%																
		Maintenance Interface	15						1									2%															
		Weather Interface	16			1													2%														
		Aspiration Interface	17								1									2%													
		Attackable Interface	18			1															2%												
		Detection Interface	19			1		1														2%											
		Attachment Interface	20										1										2%										
		Higher Level Control Interface	21						1															2%									
		Collision Interface	22	1		1																			2%								
		Inter-Vehicular Interface	23						1																	2%							
		Transport Interface	24				1																				2%						
		Docking Interface	25			1																						2%					
		GPS Interface	26						1																				2%				
			27						1																					2%			
			28																												2%		
			29			1		1																								2%	
			30	1	1																												2%

Physical Architecture Views

Block Diagram and Design Structure Matrix (DSM)

- In the case of Physical Architecture:
  - The blocks in the LA diagram become rows and columns of the DSM
  - The connection lines in the LA diagram become subsystems or components in the DSM shown in rows and columns
- Both views provide visualizations of hierarchy
  - How the physical system has been partitioned into physical sub-systems that are physically related (connected, contained, adjacent, etc.)
  - The DSM additionally shows the interactions of subsystems

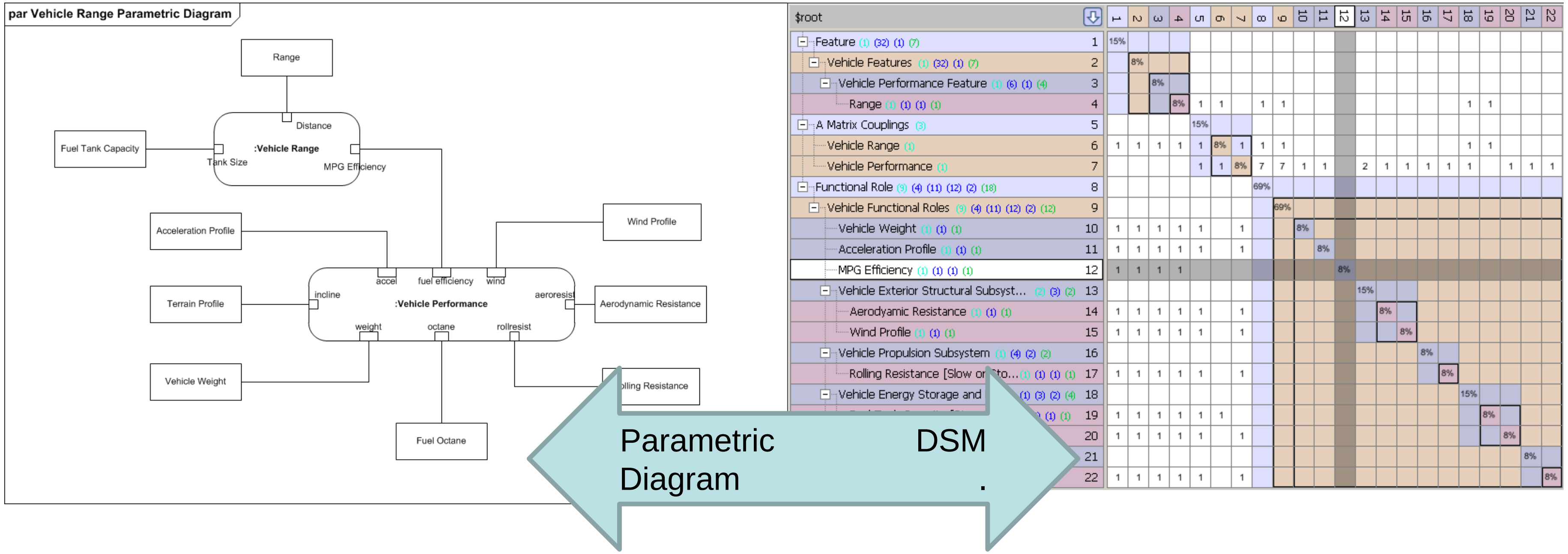


Acknowledgement: Influenced by related physical architecture work of John Thomas

$root		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22
Vehicle Interior	1	3%	1	1						1										1	3		
Body Exterior	2	1	3%	1																3	3		
Body Structure	3	1	1	3%										1									
Body Control Module (BCM)	4				3%																		
Vehicle Body Ref	5	2	2	2		3%				1				1						4	6		
Exhaust System	6						3%							1						1	3		
Fuel Supply System	7							11%						1		2				1	3		
Brakes	8								3%			1	1	1						1	3		
Steering	9	1								3%			1	1						1	3		
Suspension	10										3%		1	1									
Wheels	11								1			3%	1										
Vehicle Driveline	12								1	1	1	1	3%	1		1	1			1	3		
Vehicle Frame	13			1			1	1	1	1	1		1	3%			1						
Vehicle Chassis Ref	14	1		1			1	1	2	2	2		4	6	3%		2			5	15		
Engine System	15															31%				1			1
Transmission	16												1	1			3%	5		3	5		
Powertrain Co ol Module (PCM)	17																5	3%		1	5		
Powertrain Re	18												1	1			5	5	3%	4	10		
ement/Distributio...	19	1	3				1	1	1	1			1			3	3	1		3%			1
k	20	3	3				1	3	3	3			3				5	5			3%		
Module (ECM)	21																					3%	
	22															2				1			3%

Domain Structure Matrix (DSM) View of Same

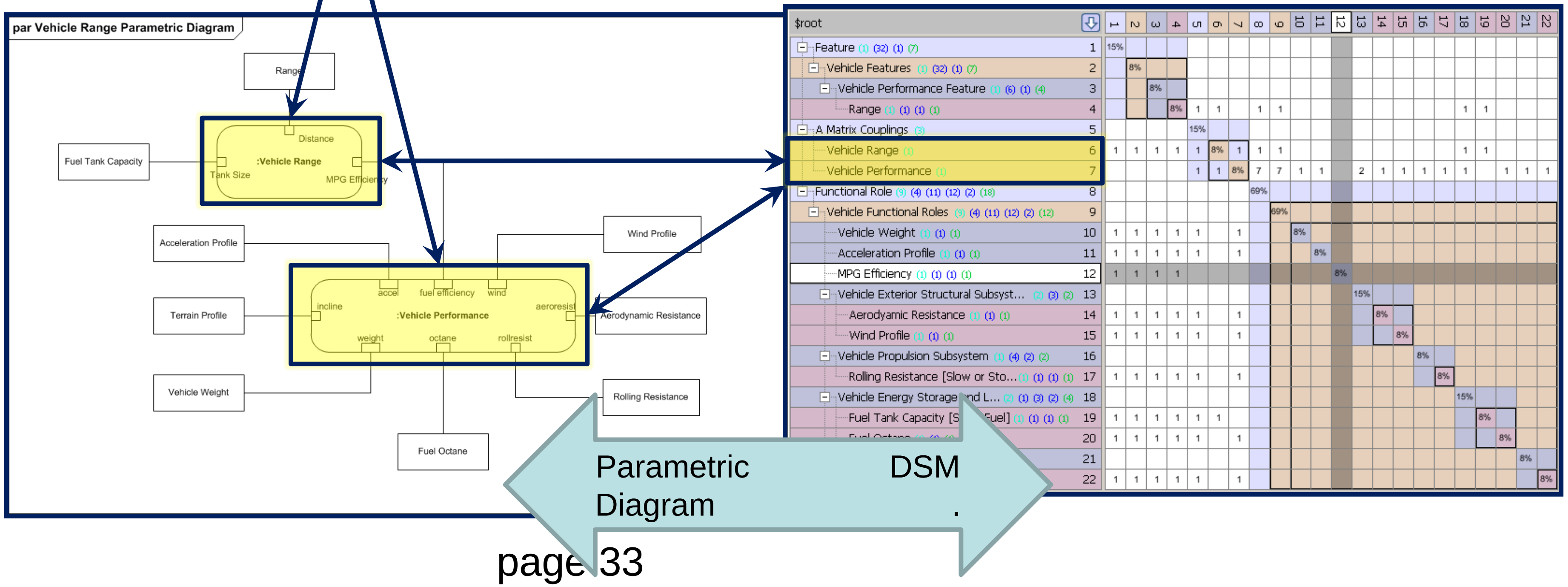
- In the case of Coupled Parameters (attributes):
  - Attributes become row and column headings in the DSM
  - This includes adding rows and columns to the Logical Architecture DSM, showing attributes of the Logical Subsystems
  - Connection lines in the drawing become marked cells in the DSM
- Both views convey the same information:
  - Which attributes are coupled (impact each others' values)



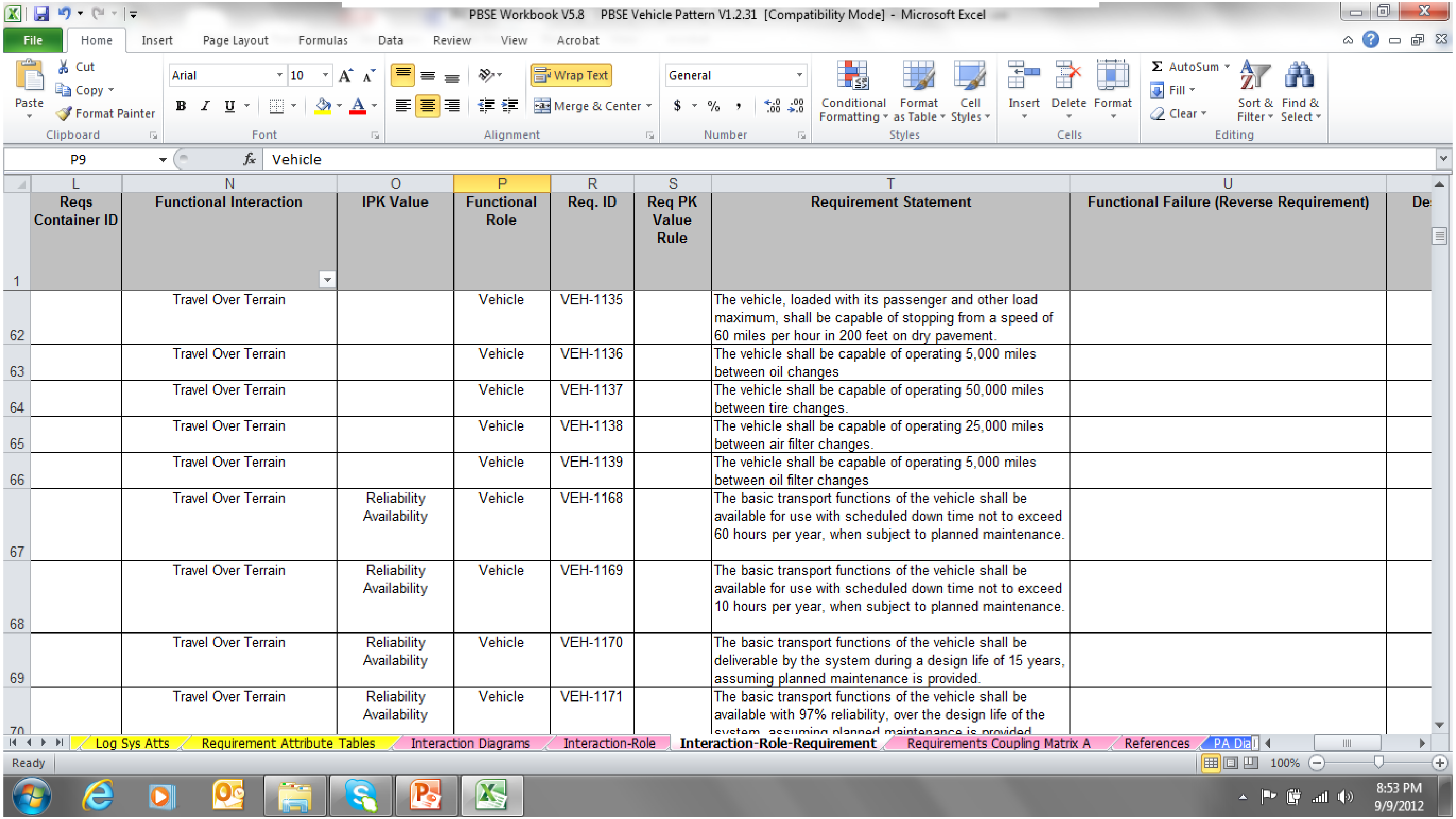
$root		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22
Feature (1) (32) (1) (7)	1	15%																					
Vehicle Features (1) (32) (1) (7)	2		8%																				
Vehicle Performance Feature (1) (6) (1) (4)	3			8%																			
Range (1) (1) (1) (1)	4				8%	1	1		1	1									1	1			
A Matrix Couplings (3)	5					15%																	
Vehicle Range (1)	6	1	1	1	1	1	8%	1	1	1									1	1			
Vehicle Performance (1)	7					1	1	8%	7	7	1	1		2	1	1	1	1	1		1	1	1
Functional Role (9) (4) (11) (12) (2) (18)	8								69%														
Vehicle Functional Roles (9) (4) (11) (12) (2) (12)	9									69%													
Vehicle Weight (1) (1) (1)	10	1	1	1	1	1		1			8%												
Acceleration Profile (1) (1) (1)	11	1	1	1	1	1		1				8%											
MPG Efficiency (1) (1) (1) (1)	12	1	1	1	1								8%										
Vehicle Exterior Structural Subsyst... (2) (3) (2)	13													15%									
Aerodyamic Resistance (1) (1) (1)	14	1	1	1	1	1		1							8%								
Wind Profile (1) (1) (1)	15	1	1	1	1	1		1								8%							
Vehicle Propulsion Subsystem (1) (4) (2) (2)	16																8%						
Rolling Resistance [Slow or Sto... (1) (1) (1) (1)	17	1	1	1	1	1		1										8%					
Vehicle Energy Storage and (1) (3) (2) (4)	18																		15%				
(1) (1)	19	1	1	1	1	1	1													8%			
	20	1	1	1	1	1		1													8%		
	21																					8%	
	22	1	1	1	1	1		1															8%

Domain Structure Matrix (DSM) View of Same

- Instead of just showing which attributes are coupled, the DSM (like the Parametric Diagram) can also symbolize the named Coupling that connects them:
  - This provides a reference to a (separately documented) quantitative coupling description.
- The names of the couplings can be introduced as row and column headings, separate from the rows and columns that list the attribute names:
  - This becomes a Multi-Domain Matrix (MDM):



Requirement Statements

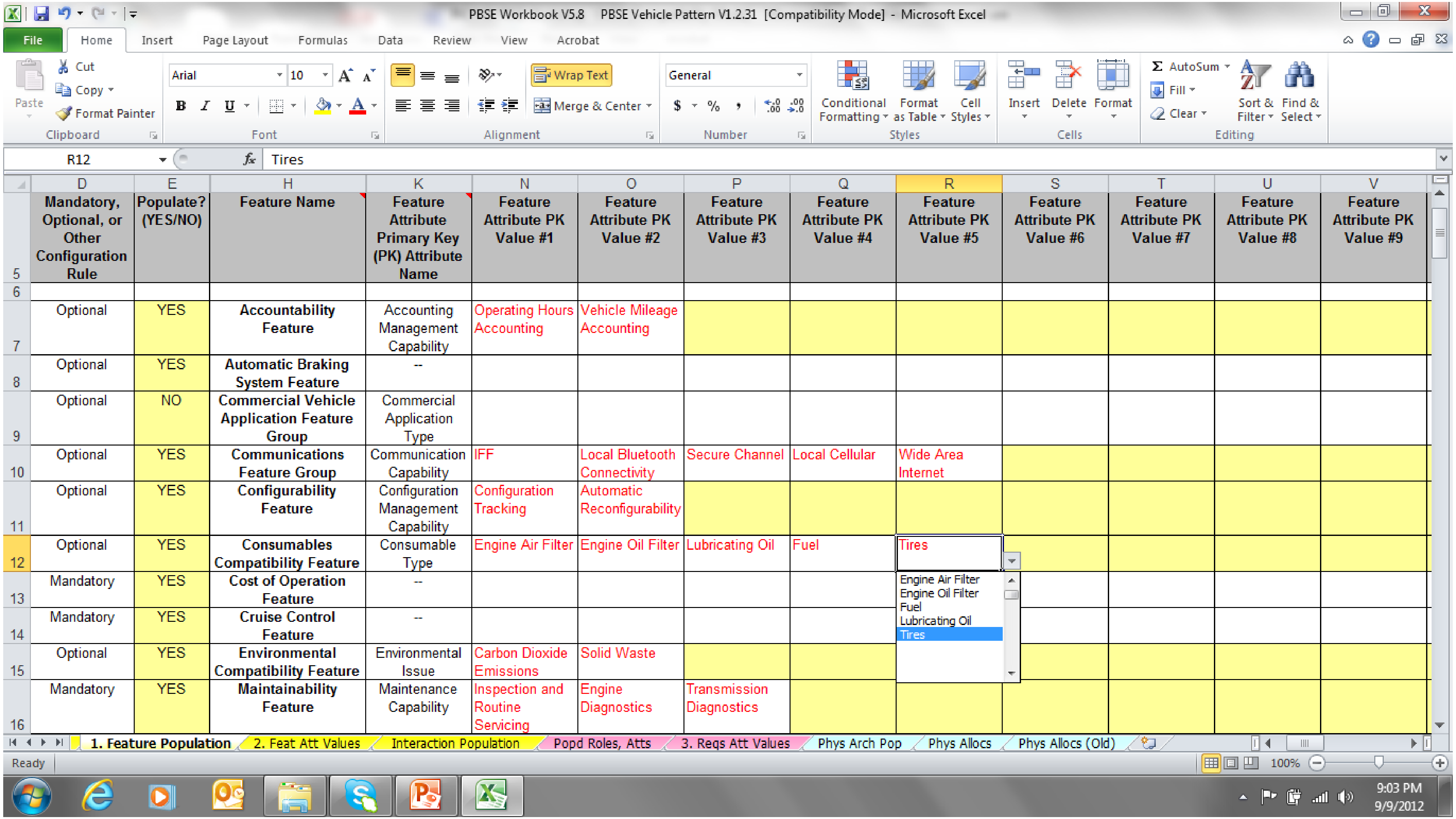


	L	N	O	P	R	S	T	U	
1	Reqs Container ID	Functional Interaction	IPK Value	Functional Role	Req. ID	Req PK Value Rule	Requirement Statement	Functional Failure (Reverse Requirement)	De
62		Travel Over Terrain		Vehicle	VEH-1135		The vehicle, loaded with its passenger and other load maximum, shall be capable of stopping from a speed of 60 miles per hour in 200 feet on dry pavement.		
63		Travel Over Terrain		Vehicle	VEH-1136		The vehicle shall be capable of operating 5,000 miles between oil changes		
64		Travel Over Terrain		Vehicle	VEH-1137		The vehicle shall be capable of operating 50,000 miles between tire changes.		
65		Travel Over Terrain		Vehicle	VEH-1138		The vehicle shall be capable of operating 25,000 miles between air filter changes.		
66		Travel Over Terrain		Vehicle	VEH-1139		The vehicle shall be capable of operating 5,000 miles between oil filter changes		
67		Travel Over Terrain	Reliability Availability	Vehicle	VEH-1168		The basic transport functions of the vehicle shall be available for use with scheduled down time not to exceed 60 hours per year, when subject to planned maintenance.		
68		Travel Over Terrain	Reliability Availability	Vehicle	VEH-1169		The basic transport functions of the vehicle shall be available for use with scheduled down time not to exceed 10 hours per year, when subject to planned maintenance.		
69		Travel Over Terrain	Reliability Availability	Vehicle	VEH-1170		The basic transport functions of the vehicle shall be deliverable by the system during a design life of 15 years, assuming planned maintenance is provided.		
70		Travel Over Terrain	Reliability Availability	Vehicle	VEH-1171		The basic transport functions of the vehicle shall be available with 97% reliability, over the design life of the system, assuming planned maintenance is provided.		

Failure Modes Model

Physical Entity	Failure Mode
Vehicle ECM	Dead ECM
Vehicle ECM	Network Connector Open
Vehicle ECM	Network Connector Short
Vehicle ECM	Erratic ECM
Battery	Discharged Battery
Battery	Battery Cell Short
Battery	Battery Cell Open
Battery	Battery Leak
Panel Display	Fractured Display
Panel Display	Illuminator Fail
Bluetooth Module	Module Hard Fail
Bluetooth Module	Transmitter Fail
Bluetooth Module	Receiver Fail

Filling in the Feature Population Form—with Stakeholder Needs

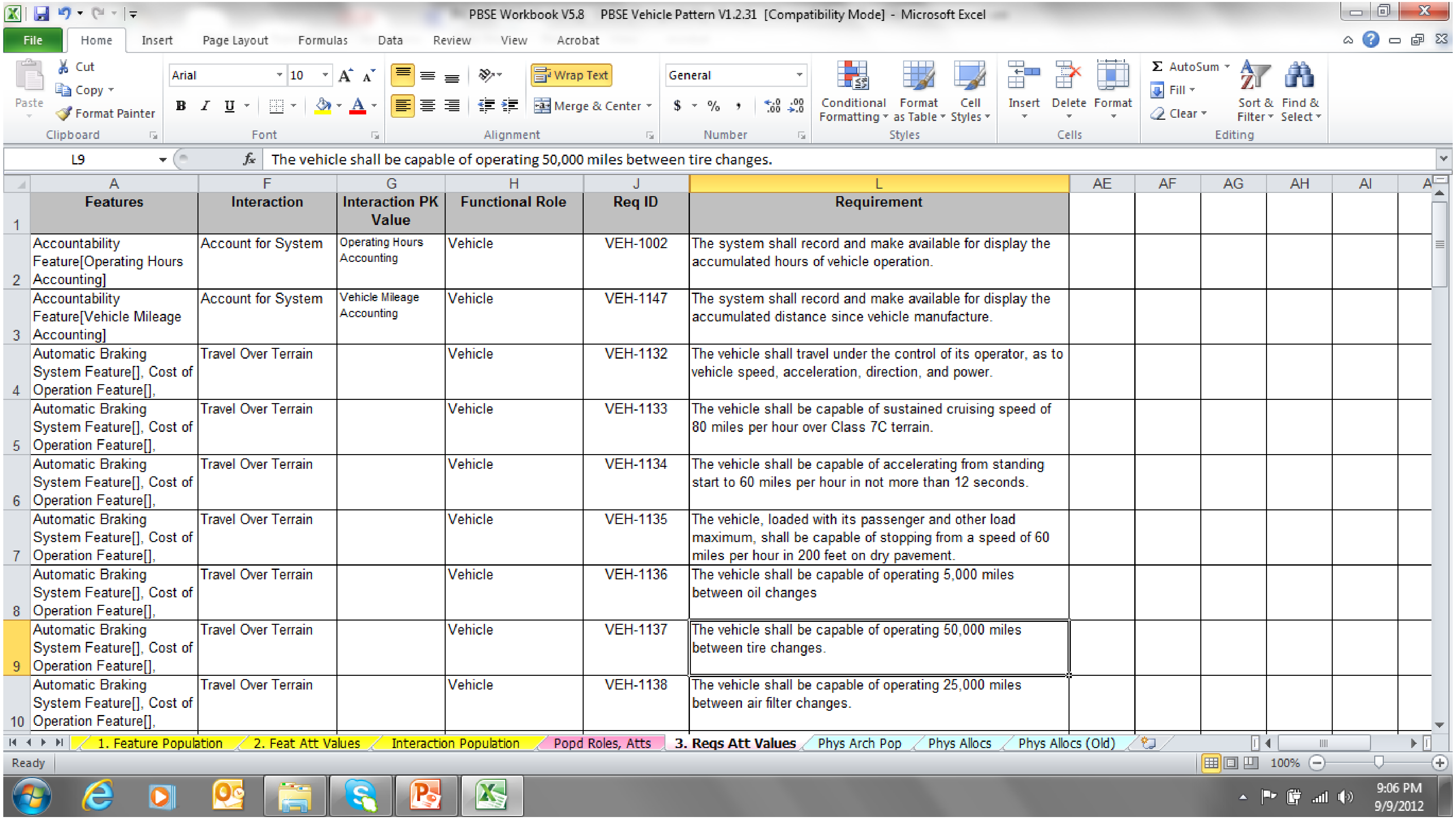


R12 | Tires

	D	E	H	K	N	O	P	Q	R	S	T	U	V
5	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 PK Value #4	Feature Attribute PK Value #5	Feature Attribute PK Value #6	Feature Attribute PK Value #7	Feature Attribute PK Value #8	Feature Attribute PK Value #9
6													
7	Optional	YES	Accountability Feature	Accounting Management Capability	Operating Hours Accounting	Vehicle Mileage Accounting							
8	Optional	YES	Automatic Braking System Feature	--									
9	Optional	NO	Commercial Vehicle Application Feature Group	Commercial Application Type									
10	Optional	YES	Communications Feature Group	Communication Capability	IFF	Local Bluetooth Connectivity	Secure Channel	Local Cellular	Wide Area Internet				
11	Optional	YES	Configurability Feature	Configuration Management Capability	Configuration Tracking	Automatic Reconfigurability							
12	Optional	YES	Consumables Compatibility Feature	Consumable Type	Engine Air Filter	Engine Oil Filter	Lubricating Oil	Fuel	Tires				
13	Mandatory	YES	Cost of Operation Feature	--									
14	Mandatory	YES	Cruise Control Feature	--									
15	Optional	YES	Environmental Compatibility Feature	Environmental Issue	Carbon Dioxide Emissions	Solid Waste							
16	Mandatory	YES	Maintainability Feature	Maintenance Capability	Inspection and Routine Servicing	Engine Diagnostics	Transmission Diagnostics						

Engine Air Filter
Engine Oil Filter
Fuel
Lubricating Oil
Tires

Resulting Auto-Populated Requirements



L9: The vehicle shall be capable of operating 50,000 miles between tire changes.

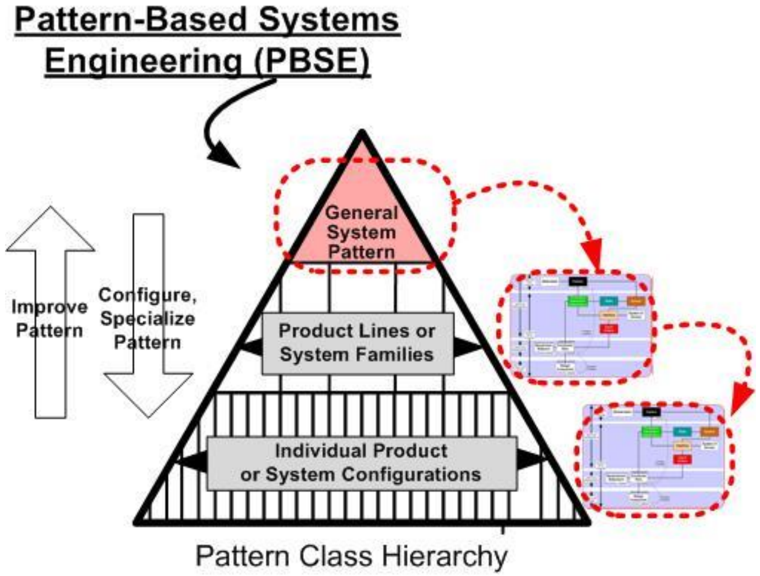
	A	F	G	H	J	L
1	**Features**	**Interaction**	**Interaction PK Value**	**Functional Role**	**Req ID**	**Requirement**
2	Accountability Feature[Operating Hours Accounting]	Account for System	Operating Hours Accounting	Vehicle	VEH-1002	The system shall record and make available for display the accumulated hours of vehicle operation.
3	Accountability Feature[Vehicle Mileage Accounting]	Account for System	Vehicle Mileage Accounting	Vehicle	VEH-1147	The system shall record and make available for display the accumulated distance since vehicle manufacture.
4	Automatic Braking System Feature[], Cost of Operation Feature[],	Travel Over Terrain		Vehicle	VEH-1132	The vehicle shall travel under the control of its operator, as to vehicle speed, acceleration, direction, and power.
5	Automatic Braking System Feature[], Cost of Operation Feature[],	Travel Over Terrain		Vehicle	VEH-1133	The vehicle shall be capable of sustained cruising speed of 80 miles per hour over Class 7C terrain.
6	Automatic Braking System Feature[], Cost of Operation Feature[],	Travel Over Terrain		Vehicle	VEH-1134	The vehicle shall be capable of accelerating from standing start to 60 miles per hour in not more than 12 seconds.
7	Automatic Braking System Feature[], Cost of Operation Feature[],	Travel Over Terrain		Vehicle	VEH-1135	The vehicle, loaded with its passenger and other load maximum, shall be capable of stopping from a speed of 60 miles per hour in 200 feet on dry pavement.
8	Automatic Braking System Feature[], Cost of Operation Feature[],	Travel Over Terrain		Vehicle	VEH-1136	The vehicle shall be capable of operating 5,000 miles between oil changes
9	Automatic Braking System Feature[], Cost of Operation Feature[],	Travel Over Terrain		Vehicle	VEH-1137	The vehicle shall be capable of operating 50,000 miles between tire changes.
10	Automatic Braking System Feature[], Cost of Operation Feature[],	Travel Over Terrain		Vehicle	VEH-1138	The vehicle shall be capable of operating 25,000 miles between air filter changes.

1. Stakeholder Features and Scenarios: Better stakeholders alignment sooner

- Alignment with stakeholders is critical to program success.
- That alignment can be achieved earlier and maintained stronger using:
  - Stakeholder Feature Pattern: Aligns understanding of system capabilities (base as well as options) and the nature of their value to stakeholders
  - Scenario Pattern: Aligns understanding of the concepts of operations, support, manufacture, distribution, other life cycle situations; accelerates alignment of system documentation, training, and communication.
- Both of these are “pattern configurations” directly generated from the System Pattern—not separate and unsynchronized information.

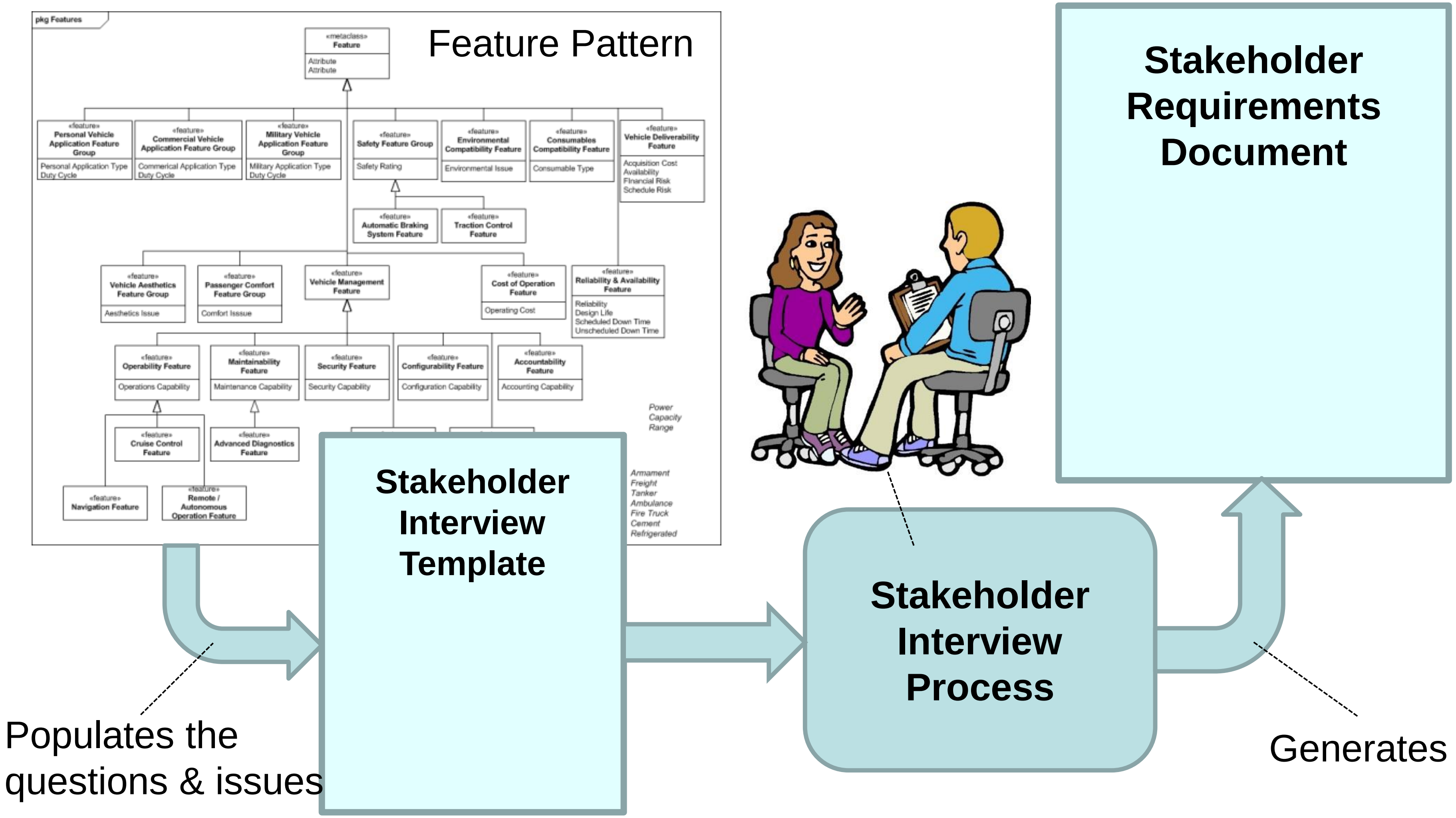
1. Using the Feature Pattern to Rapidly Capture & Validate Stakeholder Requirements: An Example

- Concept: The Feature Pattern is a powerful tool for establishing Stakeholder Requirements—as a “configuration” of Feature Pattern.
- By “configuration”, we mean that individual Features from the Pattern are (1) either populated or de-populated, and (2) their Feature Attributes (parameters) are given values:



- These can be expressed (1) as configured Feature objects and their attribute values or (2) as sentence-type statements if desired, but in any case the degrees of freedom (stakeholder choices) are brought into clear focus.

Using the Feature Pattern to Rapidly Capture & Validate Stakeholder Requirements: An Example



Feature Pattern

Stakeholder Interview Template

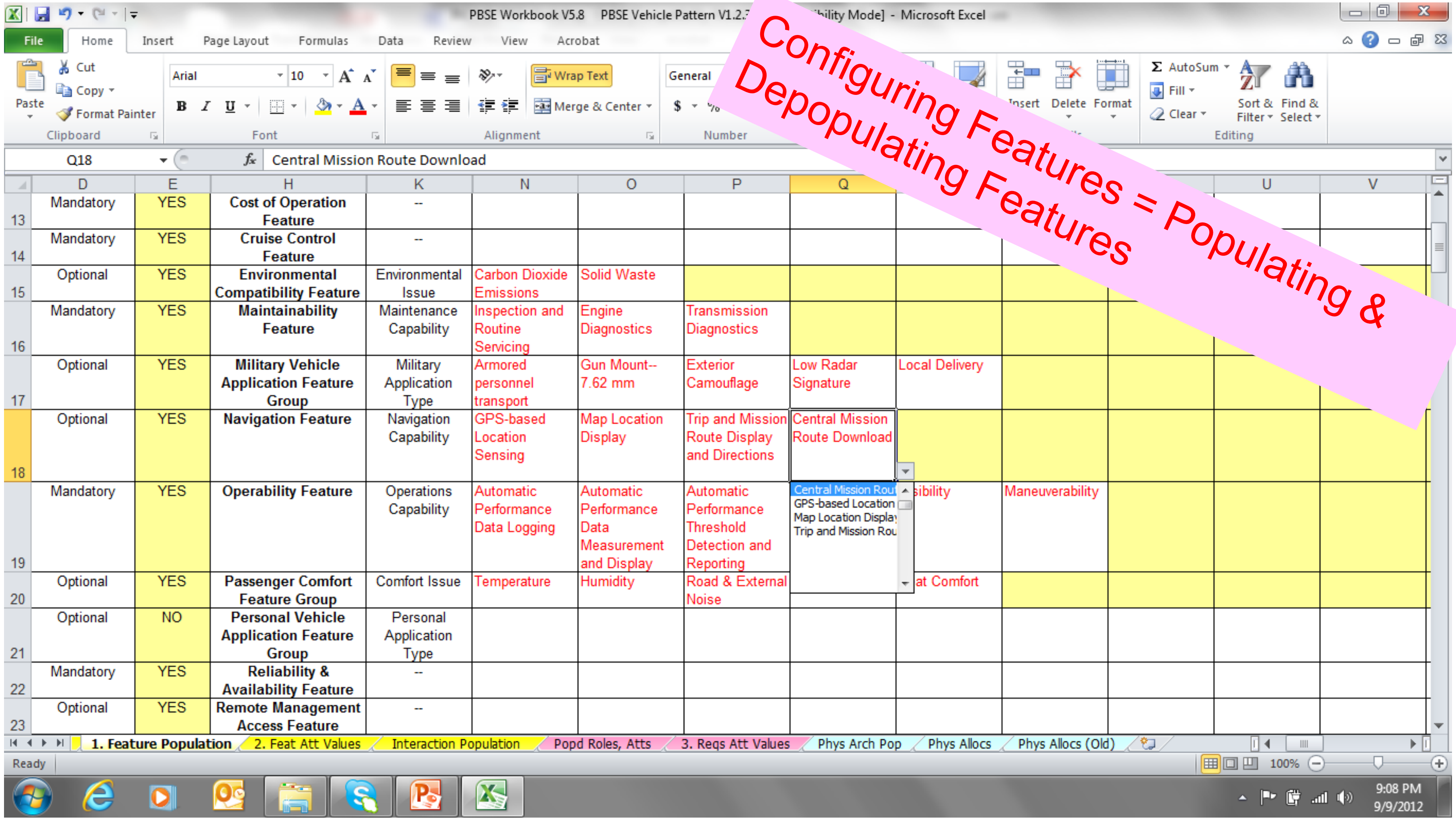
Stakeholder Interview Process

Stakeholder Requirements Document

Populates the questions & issues

Generates

1. Using the Feature Pattern to Rapidly Capture & Validate Stakeholder Requirements: An Example



Configuring Features = Populating & Depopulating Features

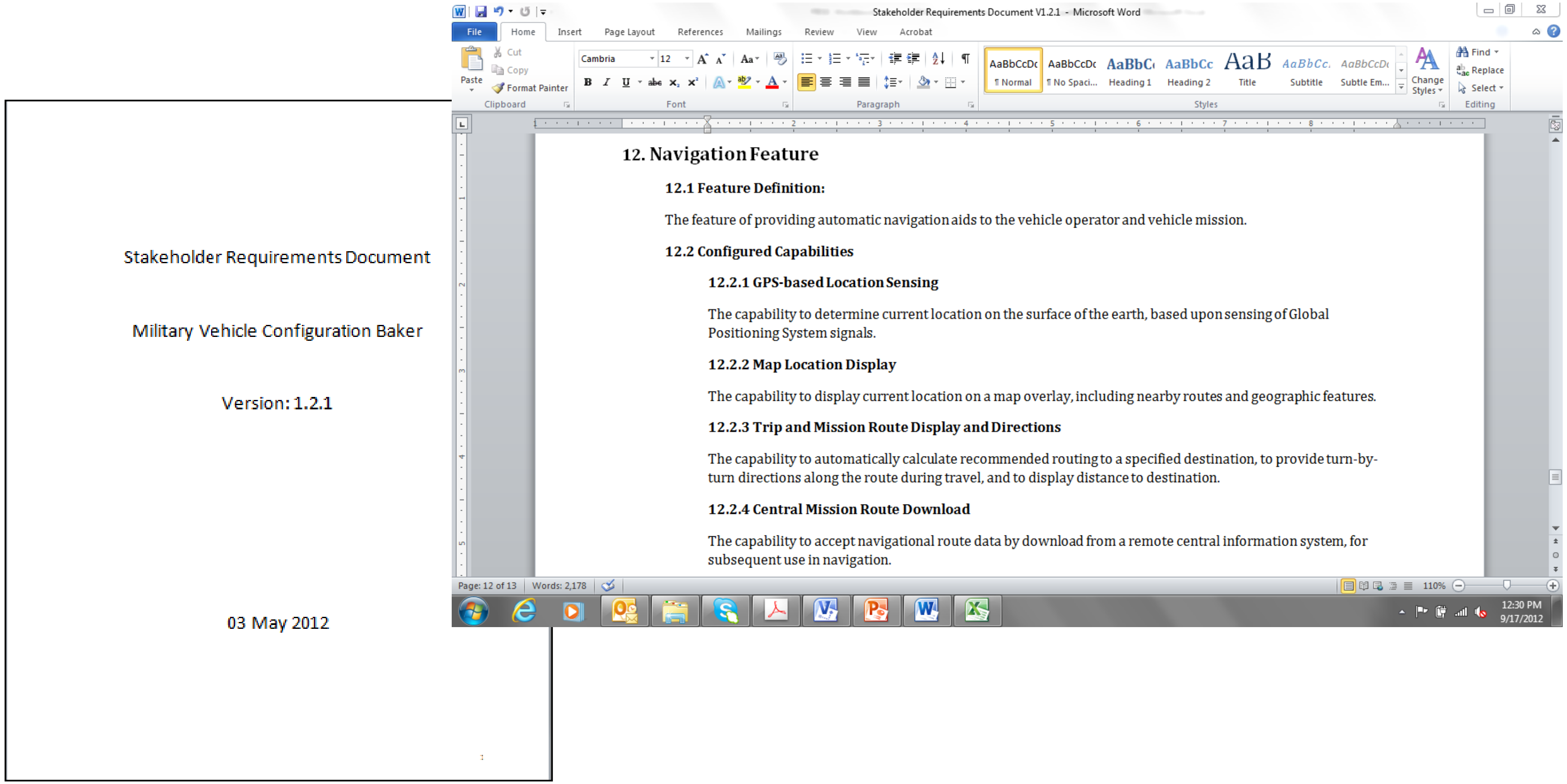
Q18 *fx* Central Mission Route Download

	D	E	H	K	N	O	P	Q				U	V
13	Mandatory	YES	**Cost of Operation Feature**	--									
14	Mandatory	YES	**Cruise Control Feature**	--									
15	Optional	YES	**Environmental Compatibility Feature**	Environmental Issue	Carbon Dioxide Emissions	Solid Waste							
16	Mandatory	YES	**Maintainability Feature**	Maintenance Capability	Inspection and Routine Servicing	Engine Diagnostics	Transmission Diagnostics						
17	Optional	YES	**Military Vehicle Application Feature Group**	Military Application Type	Armored personnel transport	Gun Mount--7.62 mm	Exterior Camouflage	Low Radar Signature	Local Delivery				
18	Optional	YES	**Navigation Feature**	Navigation Capability	GPS-based Location Sensing	Map Location Display	Trip and Mission Route Display and Directions	Central Mission Route Download					
19	Mandatory	YES	**Operability Feature**	Operations Capability	Automatic Performance Data Logging	Automatic Performance Data Measurement and Display	Automatic Performance Threshold Detection and Reporting		sibility	Maneuverability			
20	Optional	YES	**Passenger Comfort Feature Group**	Comfort Issue	Temperature	Humidity	Road & External Noise		at Comfort				
21	Optional	NO	**Personal Vehicle Application Feature Group**	Personal Application Type									
22	Mandatory	YES	**Reliability & Availability Feature**	--									
23	Optional	YES	**Remote Management Access Feature**	--									

Central Mission Rou
GPS-based Location
Map Location Display
Trip and Mission Rou

1. Feature Population | 2. Feat Att Values | Interaction Population | Popd Roles, Atts | 3. Reqs Att Values | Phys Arch Pop | Phys Allocs | Phys Allocs (Old)

1. Using the Feature Pattern to Rapidly Capture & Validate Stakeholder Requirements: An Example



Stakeholder Requirements Document

Military Vehicle Configuration Baker

Version: 1.2.1

03 May 2012

12. Navigation Feature

12.1 Feature Definition:

The feature of providing automatic navigation aids to the vehicle operator and vehicle mission.

12.2 Configured Capabilities

12.2.1 GPS-based Location Sensing

The capability to determine current location on the surface of the earth, based upon sensing of Global Positioning System signals.

12.2.2 Map Location Display

The capability to display current location on a map overlay, including nearby routes and geographic features.

12.2.3 Trip and Mission Route Display and Directions

The capability to automatically calculate recommended routing to a specified destination, to provide turn-by-turn directions along the route during travel, and to display distance to destination.

12.2.4 Central Mission Route Download

The capability to accept navigational route data by download from a remote central information system, for subsequent use in navigation.

1. Using the Feature Pattern to Rapidly Capture & Validate Stakeholder Requirements

- Benefits:
  - A more complete set of stakeholder requirements—reduce omissions;
  - Stronger alignment with stakeholders, sooner—surface issues earlier;
  - Pattern identifies classes of stakeholders that might have been missed;
  - Pattern makes very clear the difference between Stakeholder Requirements versus Design Constraints or Technical Requirements;
  - The Pattern provides a clear place to accumulate new learning (e.g., additional Features);
  - Sets up subsequent uses of Feature Pattern in support of Trade Space, Risk Management, FMEA “effects”, and other applications.
- No free lunch:
  - Interviewer needs to be knowledgeable about the Features;
  - Stakeholders won’t have all the answers—find the right representative;
  - Stakeholder representatives need know they are formal representatives;
  - The Feature Pattern needs to be relatively complete.

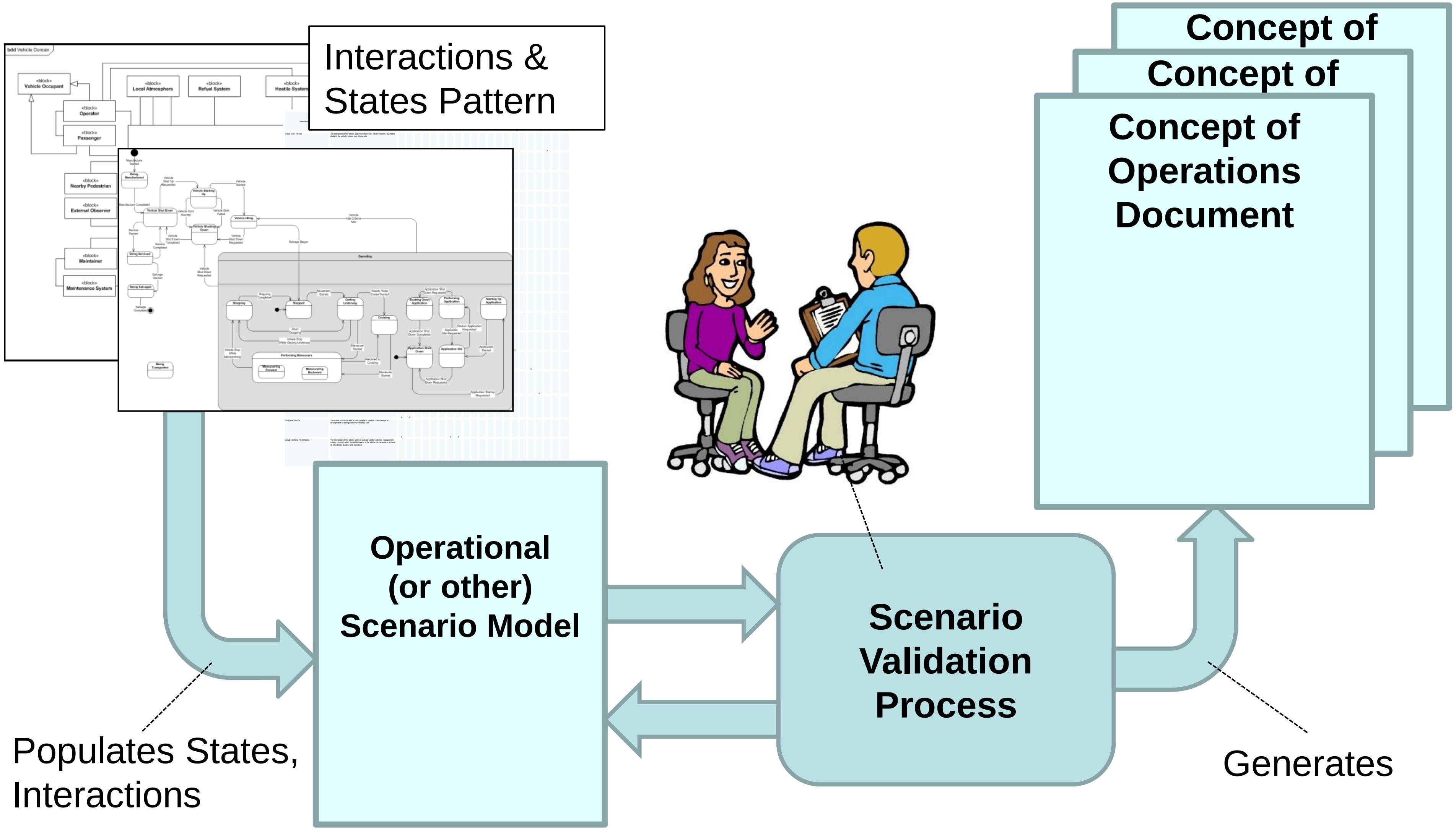
How do I know whether I have all the Features?

- This is why we use a Pattern!
  - Moves problem to the builder of the original pattern, plus maintainer.
- Related key points for the builder of the Feature Pattern:
  - First, identify all the Stakeholder classes
  - Then, all the Features for each Stakeholder class
  - Validate the Features with their Stakeholder Representatives
  - Then, make sure all the Interactions are reviewed for associated Feature value
  - There are well-known abstract Feature classes (e.g., Maintainability)
- Every time we discover another Feature, we add it to the Pattern; for example:
  - Every argument / decision should invoke trade space Features as its ultimate rationale – a new one might appear during an argument.
  - Every impactful Failure Mode should cause Feature impacting Effects – a new one might appear while discussing a Failure Mode.

1. Using the Interactions & States Pattern to Rapidly Generate & Validate Scenarios: An Example

- Concept: Scenarios can be efficiently generated, as single thread tracings through the configured pattern State Model;
- Each scenario "tells a story" within the system's life cycle—operations, maintenance, or other CONOPS type view;
- Early in life cycle: Stakeholders validate (or give feedback) scenario;
- Later in life cycle: Generates base data for training and documentation, as well as test plans;
- Akin to typical Use Case process, but easier maintained ongoing as a part of the configured pattern;
- Reference: Operational Views (OV)

1. Using the Interactions & States Pattern to Rapidly Generate & Validate Scenarios: An Example



Interactions & States Pattern

Populates States, Interactions

Operational (or other) Scenario Model

Scenario Validation Process

Concept of

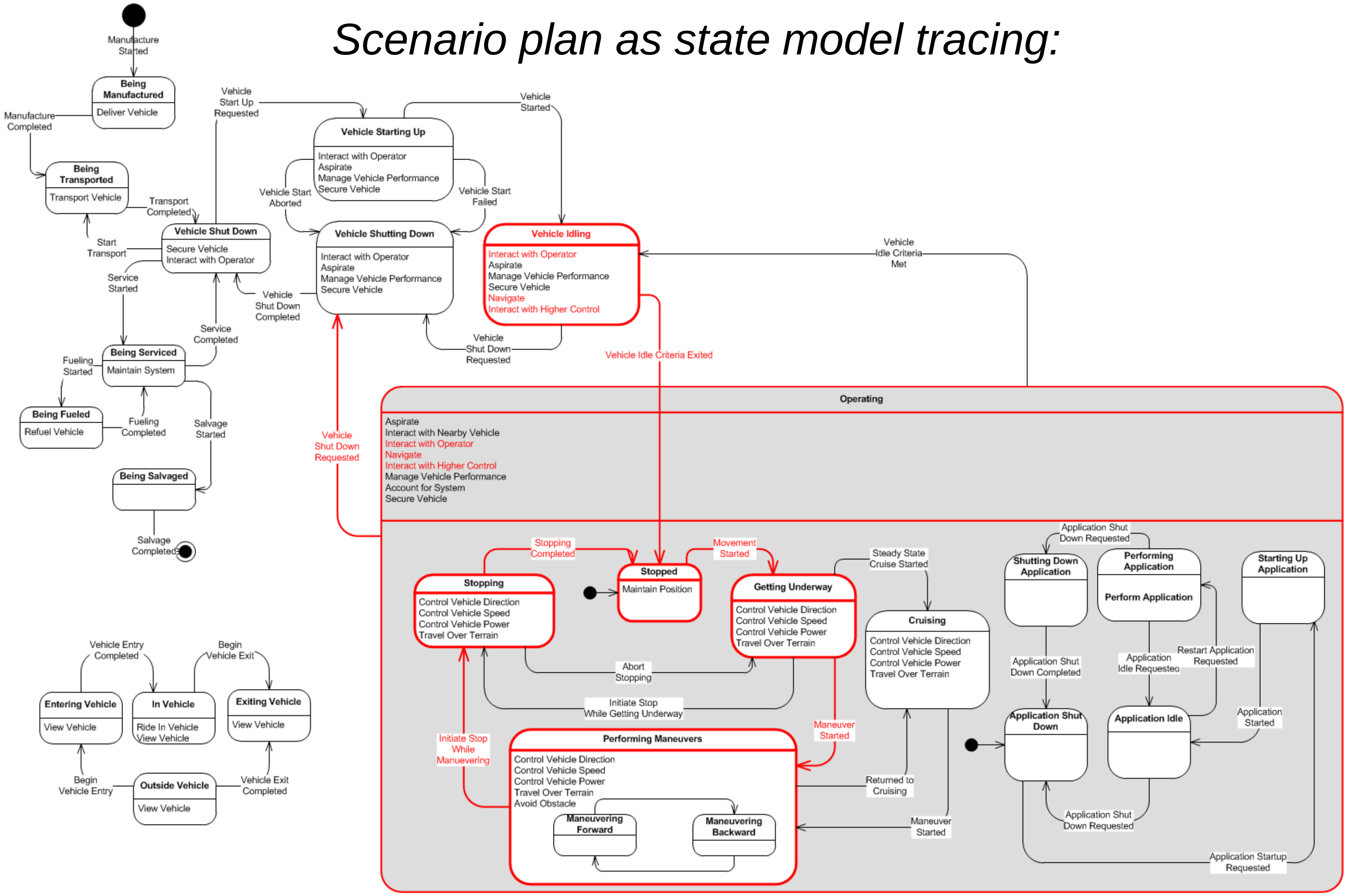
Concept of

Concept of Operations Document

Generates

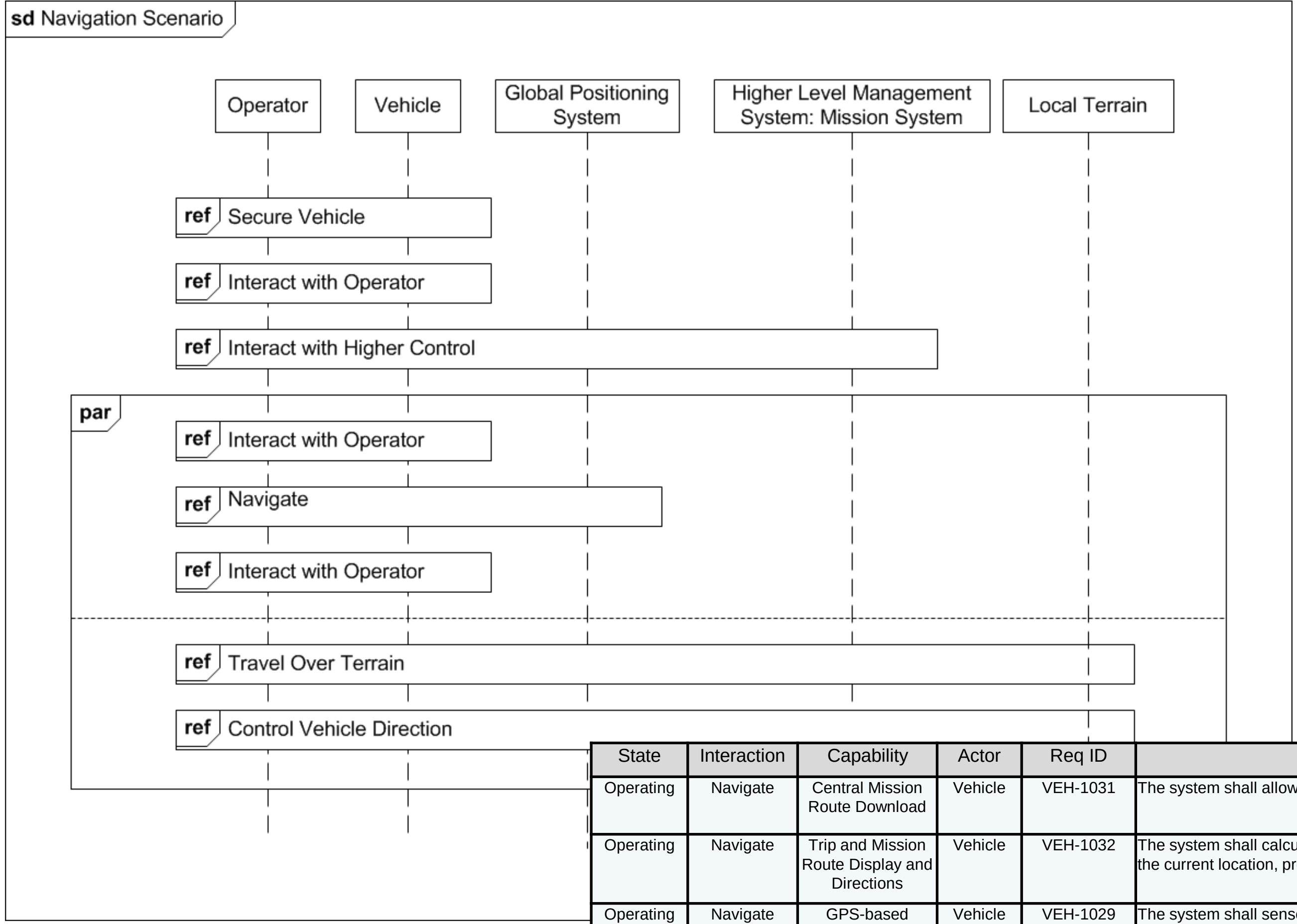
1. Using the Interactions & States Pattern to Rapidly Generate & Validate Scenarios: An Example

Scenario plan as state model tracing:



1. Using the Interactions & States Pattern to Rapidly Generate & Validate Scenarios: An Example

Scenario plan as sequence diagram and requirements:



State	Interaction	Capability	Actor	Req ID	Requirement
Operating	Navigate	Central Mission Route Download	Vehicle	VEH-1031	The system shall allow the operator to select a pre-stored route for travel on a mission.
Operating	Navigate	Trip and Mission Route Display and Directions	Vehicle	VEH-1032	The system shall calculate and display a recommended route to an operator-specified destination from the current location, providing turn-by-turn en route directions and progress tracking.
Operating	Navigate	GPS-based Location Sensing	Vehicle	VEH-1029	The system shall sense the location of the vehicle by accessing the Global Positioning System (GPS) satellite constellation and computing location on the surface of the earth, accurate to 10 feet.
Operating	Navigate	Map Location Display	Vehicle	VEH-1030	The system shall display position of the vehicle on a pre-stored graphic map presentation, including major road and geographic features, updating while enroute to reflect travel of the vehicle.
Operating	Navigate	GPS-based Location Sensing	Vehicle	VEH-1033	The system shall display to the vehicle operator a location confidence indicator, signaling whether accurate GPS location sensing is currently available.

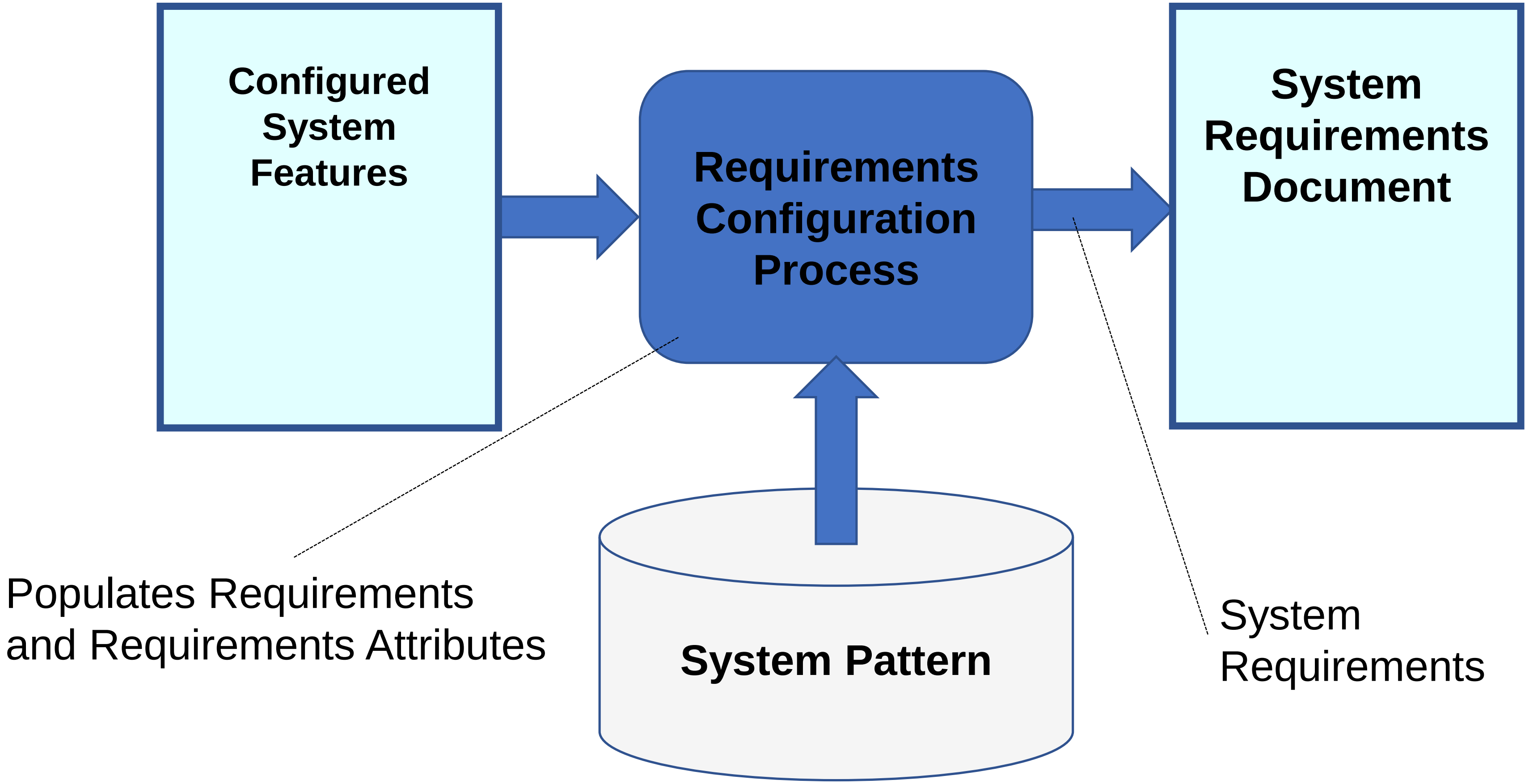
1. Using the Interactions & States Pattern to Rapidly Generate & Validate Scenarios

- Benefits:
  - A more complete set of scenarios—reduces omissions;
  - Easier to generate from pattern;
  - Easier to keep consistent with configured system model as it evolves over the delivery and life cycle;
  - Valuable not only for initial validation, but also as seed information for generation of system training, documentation, SOPs;
  - As system requirements are configured, becomes progressively more detailed;
  - The Pattern provides a clear place to accumulate new learning (e.g., additional Scenarios);
- No free lunch:
  - The State and Interaction Pattern needs to be relatively complete.

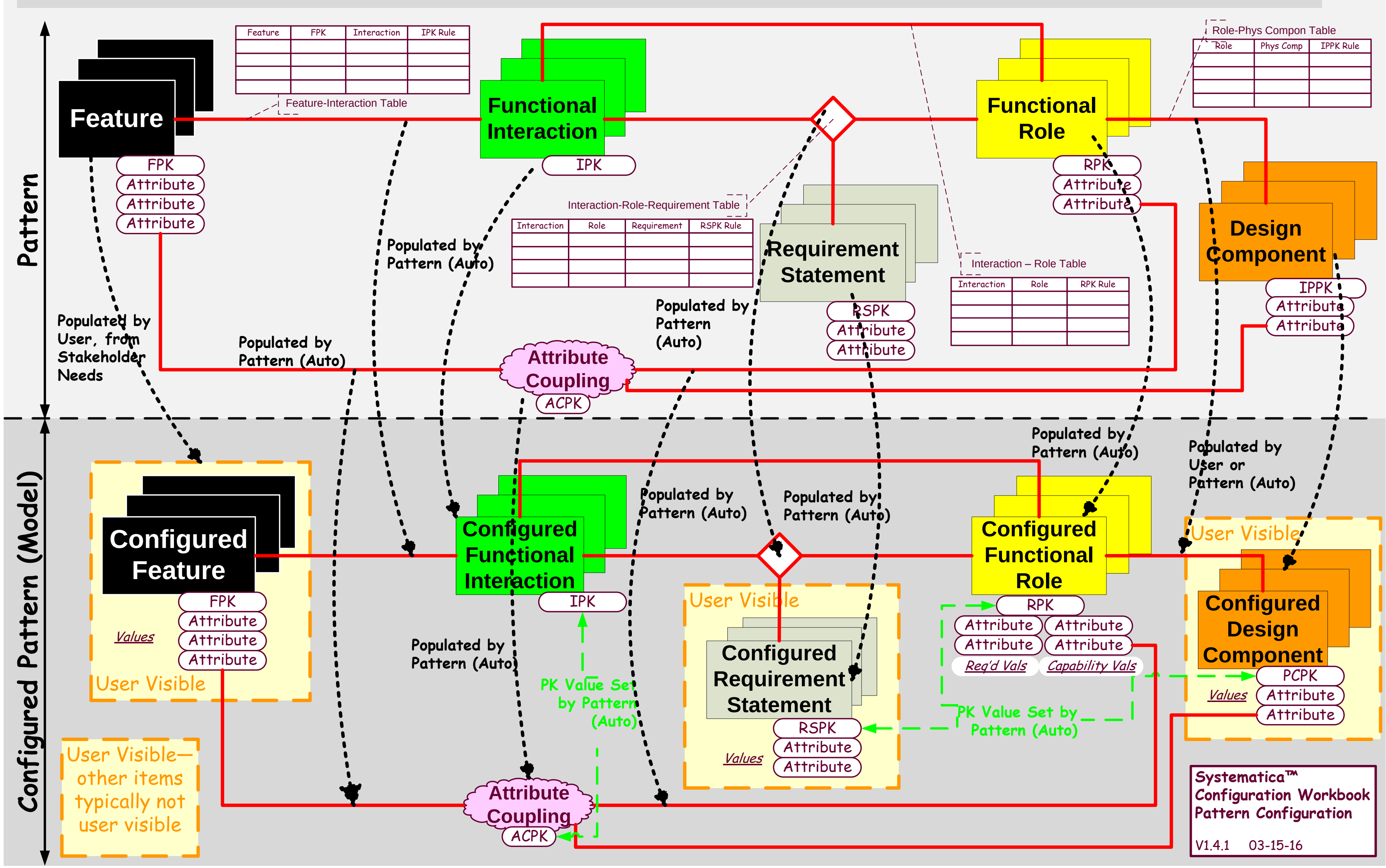
2. Using Pattern Configuration to generate better System Requirements faster: Example

- Concept: Configured System Requirements can be semi-automatically generated from Configured Features, using the System Pattern;
- Low dimensionality / degrees of freedom choices in Feature stakeholder space imply higher dimensionality / degrees of freedom choices in Requirements space:
  - The difference is made up by relationships encoded in the Pattern.

Using Pattern Configuration to generate better System Requirements faster: Example

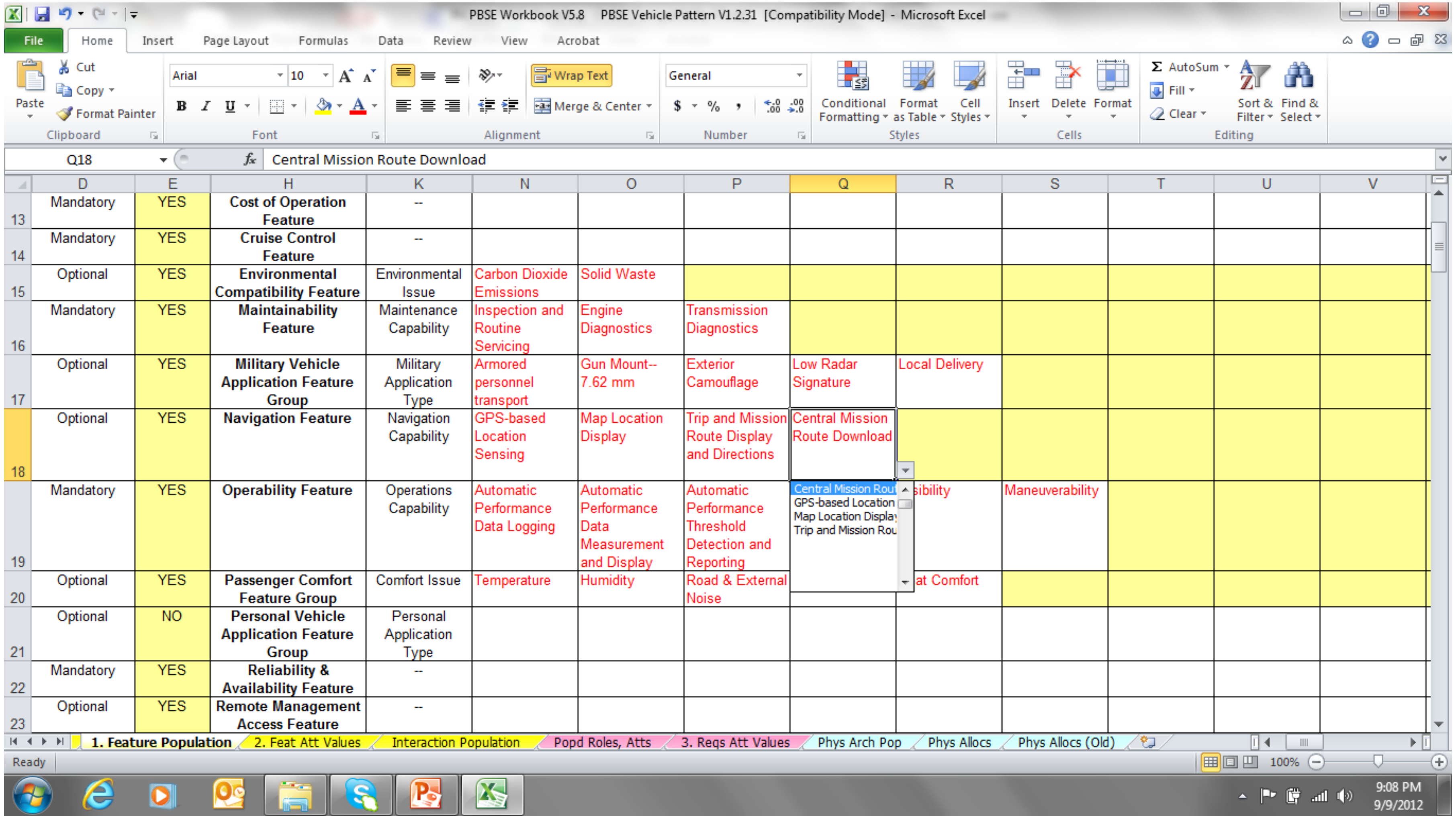


- The S*Pattern links Features to Requirements:
  - This means that populating a configuration of Features can automatically populate a configuration of Requirements--



Using a Feature Pattern to Rapidly Capture & Validate Stakeholder Requirements: An Example

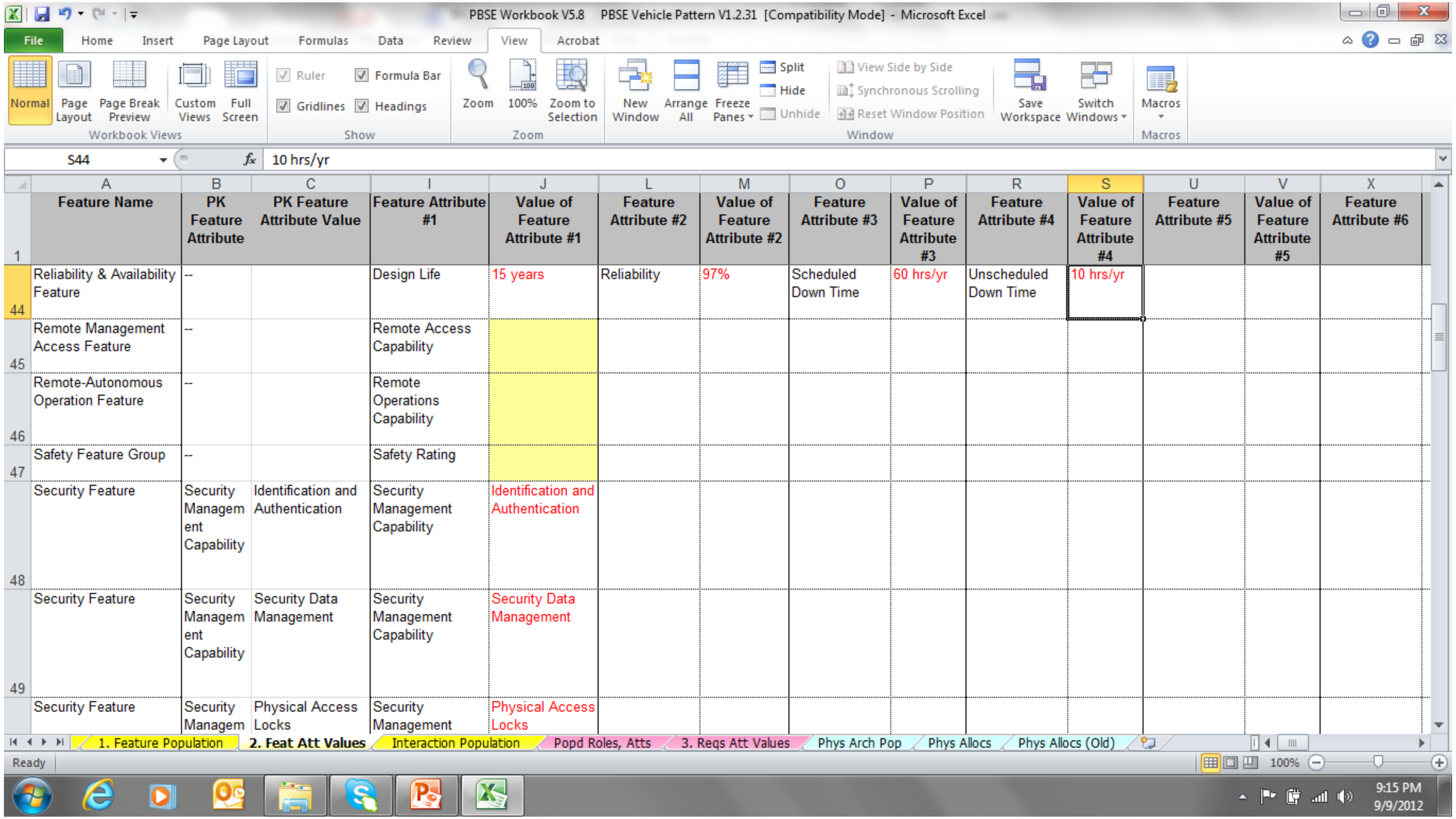
Populating / depopulating Features:



Q18 | Central Mission Route Download

	D	E	H	K	N	O	P	Q	R	S	T	U	V
13	Mandatory	YES	**Cost of Operation Feature**	--									
14	Mandatory	YES	**Cruise Control Feature**	--									
15	Optional	YES	**Environmental Compatibility Feature**	Environmental Issue	Carbon Dioxide Emissions	Solid Waste							
16	Mandatory	YES	**Maintainability Feature**	Maintenance Capability	Inspection and Routine Servicing	Engine Diagnostics	Transmission Diagnostics						
17	Optional	YES	**Military Vehicle Application Feature Group**	Military Application Type	Armored personnel transport	Gun Mount--7.62 mm	Exterior Camouflage	Low Radar Signature	Local Delivery				
18	Optional	YES	**Navigation Feature**	Navigation Capability	GPS-based Location Sensing	Map Location Display	Trip and Mission Route Display and Directions	Central Mission Route Download					
19	Mandatory	YES	**Operability Feature**	Operations Capability	Automatic Performance Data Logging	Automatic Performance Data Measurement and Display	Automatic Performance Threshold Detection and Reporting	Central Mission Rou GPS-based Location Map Location Display Trip and Mission Rou	sibility	Maneuverability			
20	Optional	YES	**Passenger Comfort Feature Group**	Comfort Issue	Temperature	Humidity	Road & External Noise		at Comfort				
21	Optional	NO	**Personal Vehicle Application Feature Group**	Personal Application Type									
22	Mandatory	YES	**Reliability & Availability Feature**	--									
23	Optional	YES	**Remote Management Access Feature**	--									

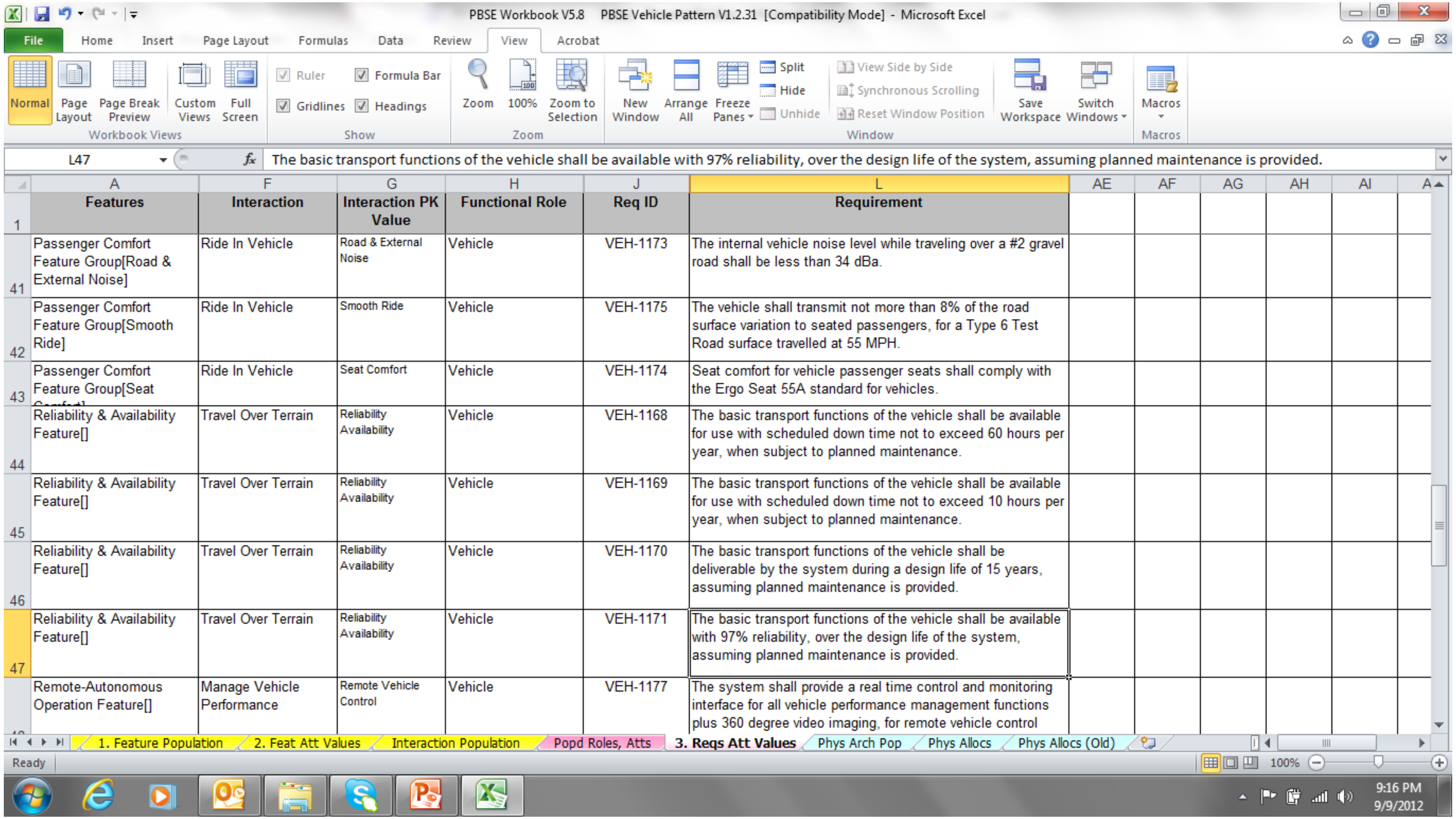
Configuring Features: Setting Feature Attribute Values



S44 10 hrs/yr

	A	B	C	I	J	L	M	O	P	R	S	U	V	X
1	**Feature Name**	**PK Feature Attribute**	**PK Feature Attribute Value**	**Feature Attribute #1**	**Value of Feature Attribute #1**	**Feature Attribute #2**	**Value of Feature Attribute #2**	**Feature Attribute #3**	**Value of Feature Attribute #3**	**Feature Attribute #4**	**Value of Feature Attribute #4**	**Feature Attribute #5**	**Value of Feature Attribute #5**	**Feature Attribute #6**
44	Reliability & Availability Feature	--		Design Life	15 years	Reliability	97%	Scheduled Down Time	60 hrs/yr	Unscheduled Down Time	10 hrs/yr			
45	Remote Management Access Feature	--		Remote Access Capability										
46	Remote-Autonomous Operation Feature	--		Remote Operations Capability										
47	Safety Feature Group	--		Safety Rating										
48	Security Feature	Security Managem ent Capability	Identification and Authentication	Security Management Capability	Identification and Authentication									
49	Security Feature	Security Managem ent Capability	Security Data Management	Security Management Capability	Security Data Management									
	Security Feature	Security Managem	Physical Access Locks	Security Management	Physical Access Locks									

Resulting Requirements: Attribute values can also be set

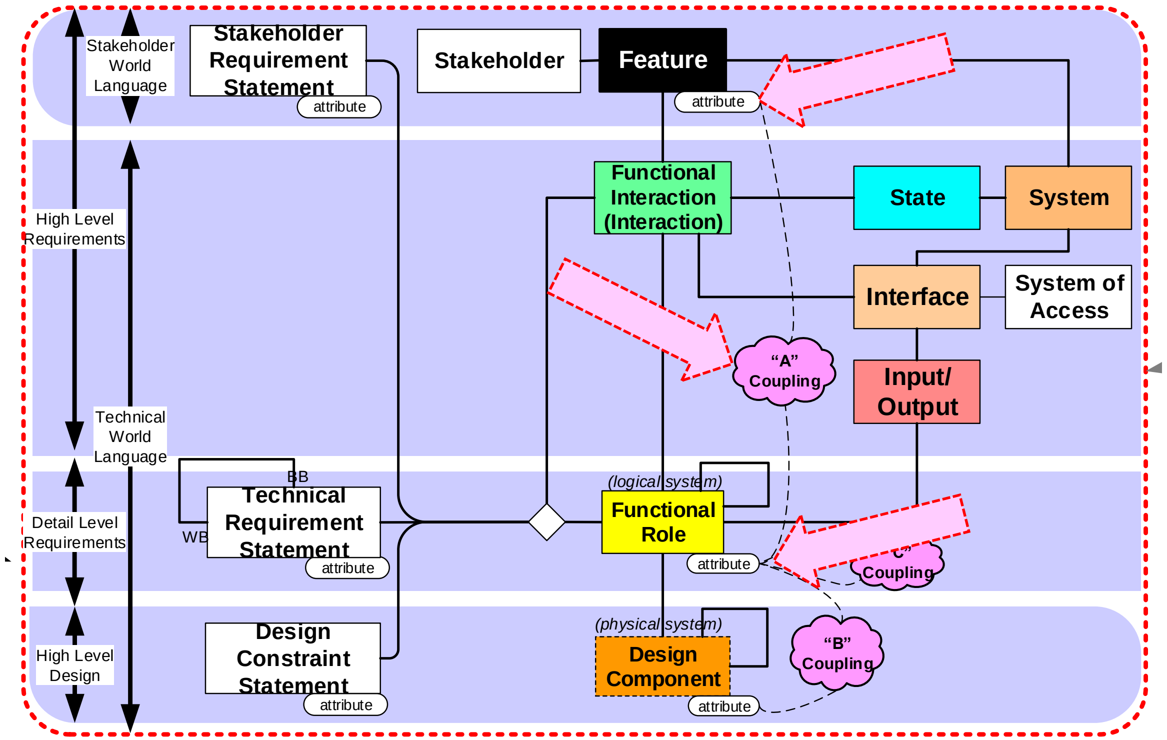


L47 fx The basic transport functions of the vehicle shall be available with 97% reliability, over the design life of the system, assuming planned maintenance is provided.

	A	F	G	H	J	L	AE	AF	AG	AH	AI
1	**Features**	**Interaction**	**Interaction PK Value**	**Functional Role**	**Req ID**	**Requirement**					
41	Passenger Comfort Feature Group[Road & External Noise]	Ride In Vehicle	Road & External Noise	Vehicle	VEH-1173	The internal vehicle noise level while traveling over a #2 gravel road shall be less than 34 dBa.					
42	Passenger Comfort Feature Group[Smooth Ride]	Ride In Vehicle	Smooth Ride	Vehicle	VEH-1175	The vehicle shall transmit not more than 8% of the road surface variation to seated passengers, for a Type 6 Test Road surface travelled at 55 MPH.					
43	Passenger Comfort Feature Group[Seat Comfort]	Ride In Vehicle	Seat Comfort	Vehicle	VEH-1174	Seat comfort for vehicle passenger seats shall comply with the Ergo Seat 55A standard for vehicles.					
44	Reliability & Availability Feature[]	Travel Over Terrain	Reliability Availability	Vehicle	VEH-1168	The basic transport functions of the vehicle shall be available for use with scheduled down time not to exceed 60 hours per year, when subject to planned maintenance.					
45	Reliability & Availability Feature[]	Travel Over Terrain	Reliability Availability	Vehicle	VEH-1169	The basic transport functions of the vehicle shall be available for use with scheduled down time not to exceed 10 hours per year, when subject to planned maintenance.					
46	Reliability & Availability Feature[]	Travel Over Terrain	Reliability Availability	Vehicle	VEH-1170	The basic transport functions of the vehicle shall be deliverable by the system during a design life of 15 years, assuming planned maintenance is provided.					
47	Reliability & Availability Feature[]	Travel Over Terrain	Reliability Availability	Vehicle	VEH-1171	The basic transport functions of the vehicle shall be available with 97% reliability, over the design life of the system, assuming planned maintenance is provided.					
	Remote-Autonomous Operation Feature[]	Manage Vehicle Performance	Remote Vehicle Control	Vehicle	VEH-1177	The system shall provide a real time control and monitoring interface for all vehicle performance management functions plus 360 degree video imaging, for remote vehicle control					

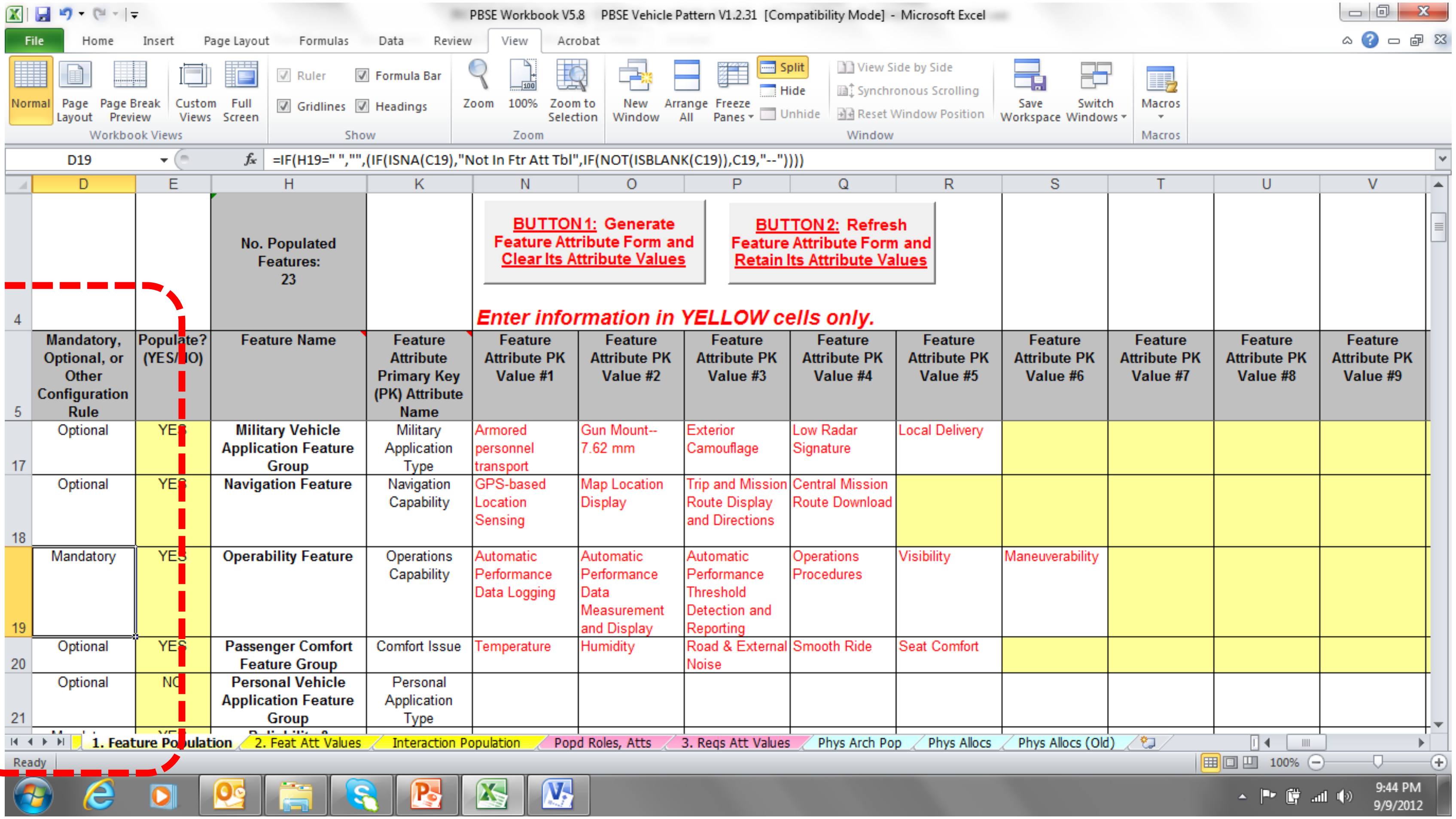
Using Pattern Configuration to generate better System Requirements faster: Example

- Requirements Attribute Value Setting:
  - A part of the configuration process
  - Example: Cruise Control Speed Stability
  - In PBSE, requirements attribute value setting can be manual, semi-automatic, or automatic—in all cases, driven by Feature Attribute Values and Attribute Couplings:



Using Pattern Configuration to generate better System Requirements faster: Example

In general, Configuration Rules are found in the Relationships that associate the model Classes, and also those that associate the model Attributes:



D19 =IF(H19=" ","",(IF(ISNA(C19),"Not In Ftr Att Tbl",IF(NOT(ISBLANK(C19)),C19,"--"))))

No. Populated Features: 23

BUTTON 1: Generate Feature Attribute Form and Clear Its Attribute Values

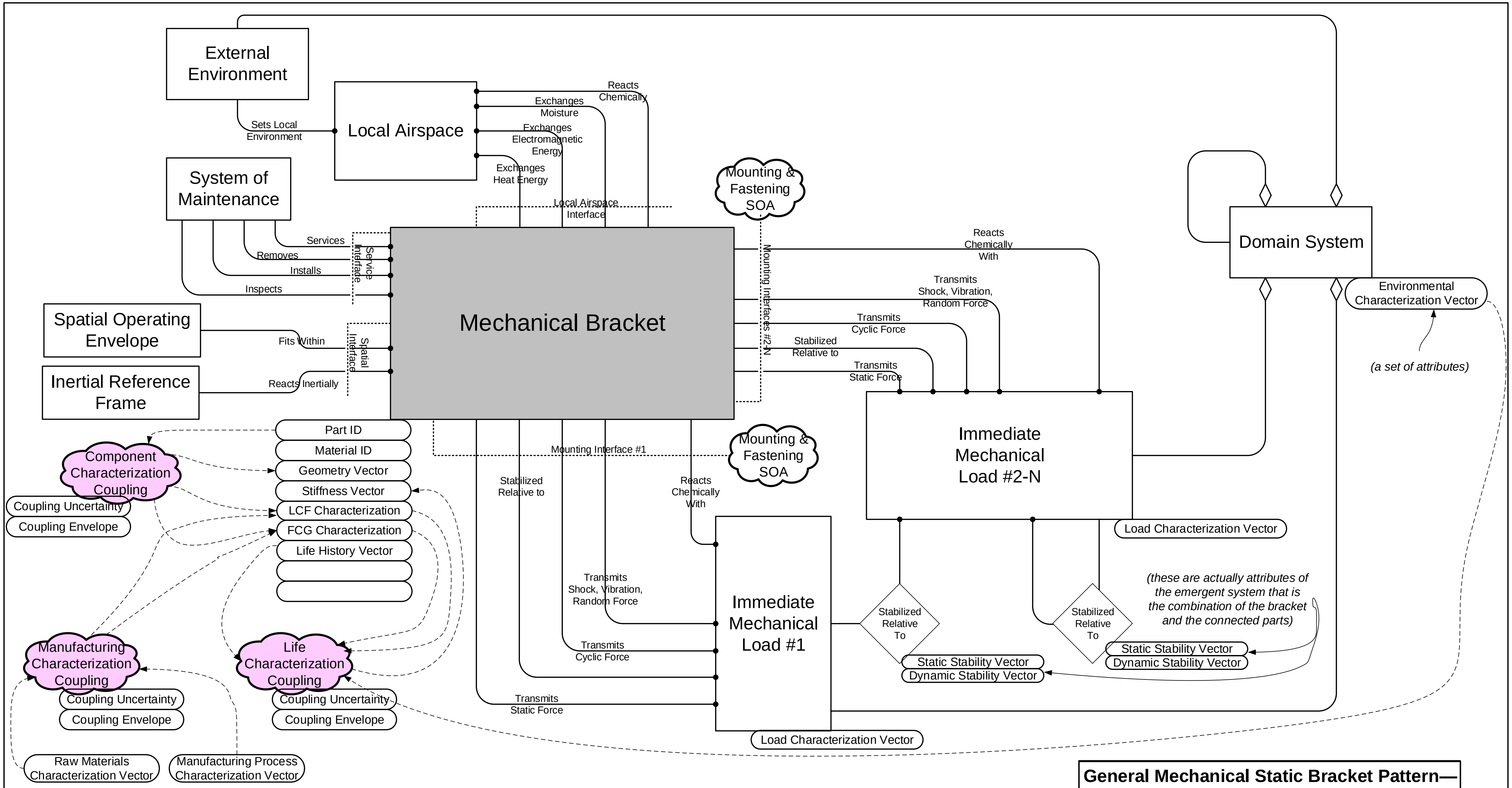
BUTTON 2: Refresh Feature Attribute Form and Retain Its Attribute Values

Enter information in YELLOW cells only.

	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 PK Value #4	Feature Attribute PK Value #5	Feature Attribute PK Value #6	Feature Attribute PK Value #7	Feature Attribute PK Value #8	Feature Attribute PK Value #9
17	Optional	YES	**Military Vehicle Application Feature Group**	Military Application Type	Armored personnel transport	Gun Mount--7.62 mm	Exterior Camouflage	Low Radar Signature	Local Delivery				
18	Optional	YES	**Navigation Feature**	Navigation Capability	GPS-based Location Sensing	Map Location Display	Trip and Mission Route Display and Directions	Central Mission Route Download					
19	Mandatory	YES	**Operability Feature**	Operations Capability	Automatic Performance Data Logging	Automatic Performance Data Measurement and Display	Automatic Performance Threshold Detection and Reporting	Operations Procedures	Visibility	Maneuverability			
20	Optional	YES	**Passenger Comfort Feature Group**	Comfort Issue	Temperature	Humidity	Road & External Noise	Smooth Ride	Seat Comfort				
21	Optional	NO	**Personal Vehicle Application Feature Group**	Personal Application Type									

Mechanical Bracket S*Pattern

- A notional early draft of part of an S*Pattern started as a placeholder until the “Design Type Cert” Project is farther along.
- Illustrates mapping of S* into what is likely going to be done by an FEA computational modeling toolset.
- See, for example, how some FEA items will be mapped to S*MTM components, attributes, couplings, etc.



These are attributes of systems in another (Manufacturing) domain of the related pattern family

Notional Early Draft

General Mechanical Static Bracket Pattern—In-Service Operational Domain Diagram

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V1.1.3
05 Jan 2018

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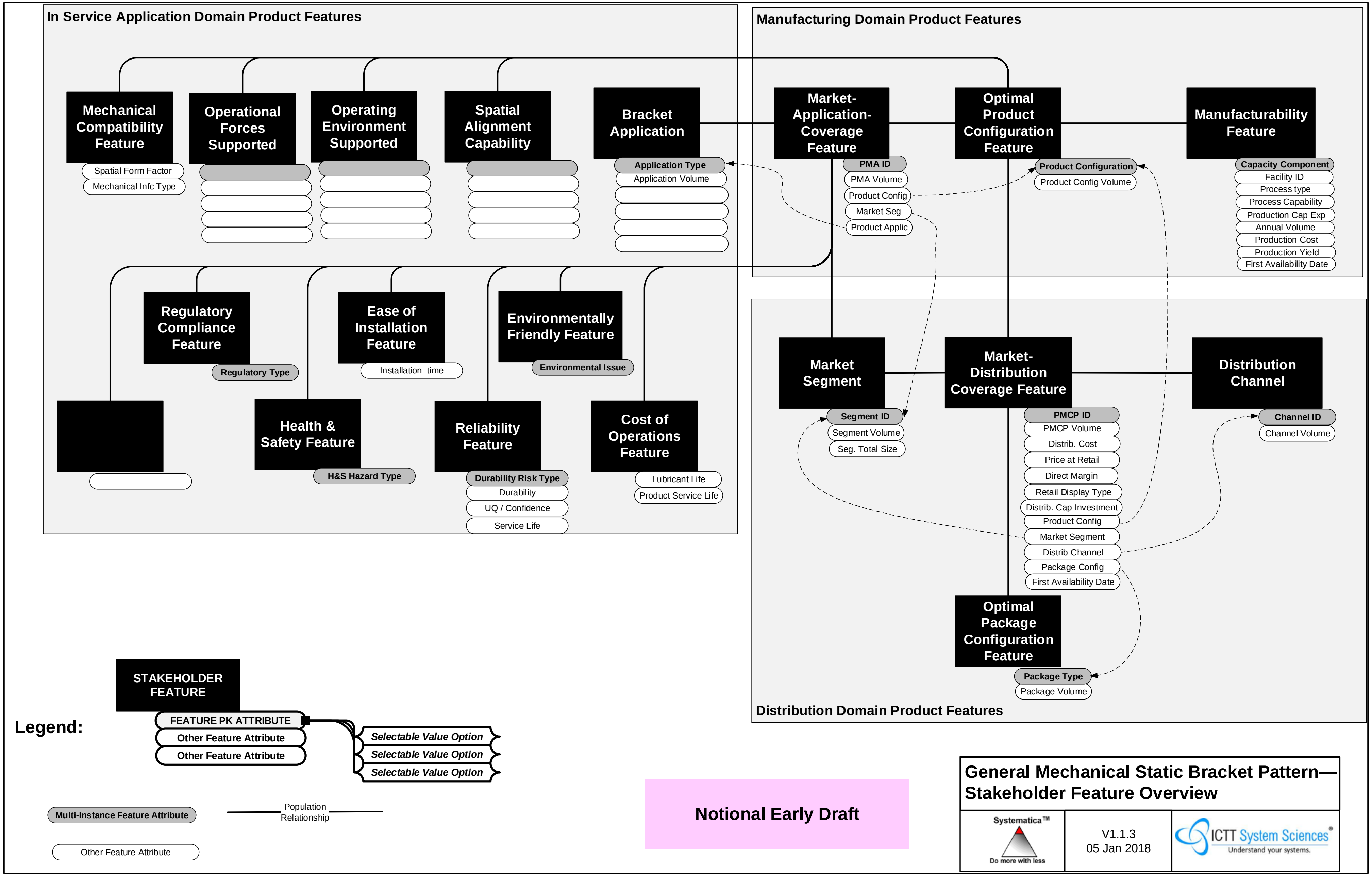

In Service Application Domain Product Features

Mechanical Compatibility Feature
- Spatial Form Factor
- Mechanical Infc Type

Operational Forces Supported

Operating Environment Supported

Spatial Alignment Capability

Bracket Application
- Application Type
- Application Volume

Regulatory Compliance Feature
- Regulatory Type

Ease of Installation Feature
- Installation time

Environmentally Friendly Feature
- Environmental Issue

Health & Safety Feature
- H&S Hazard Type

Reliability Feature
- Durability Risk Type
- Durability
- UQ / Confidence
- Service Life

Cost of Operations Feature
- Lubricant Life
- Product Service Life

Manufacturing Domain Product Features

Market-Application-Coverage Feature
- PMA ID
- PMA Volume
- Product Config
- Market Seg
- Product Applic

Optimal Product Configuration Feature
- Product Configuration
- Product Config Volume

Manufacturability Feature
- Capacity Component
- Facility ID
- Process type
- Process Capability
- Production Cap Exp
- Annual Volume
- Production Cost
- Production Yield
- First Availability Date

Distribution Domain Product Features

Market Segment
- Segment ID
- Segment Volume
- Seg. Total Size

Market-Distribution Coverage Feature
- PMCP ID
- PMCP Volume
- Distrib. Cost
- Price at Retail
- Direct Margin
- Retail Display Type
- Distrib. Cap Investment
- Product Config
- Market Segment
- Distrib Channel
- Package Config
- First Availability Date

Distribution Channel
- Channel ID
- Channel Volume

Optimal Package Configuration Feature
- Package Type
- Package Volume

Legend:

STAKEHOLDER FEATURE
- FEATURE PK ATTRIBUTE
- Other Feature Attribute
- Other Feature Attribute

- *Selectable Value Option*
- *Selectable Value Option*
- *Selectable Value Option*

Multi-Instance Feature Attribute

Population Relationship

Other Feature Attribute

Notional Early Draft

General Mechanical Static Bracket Pattern—Stakeholder Feature Overview

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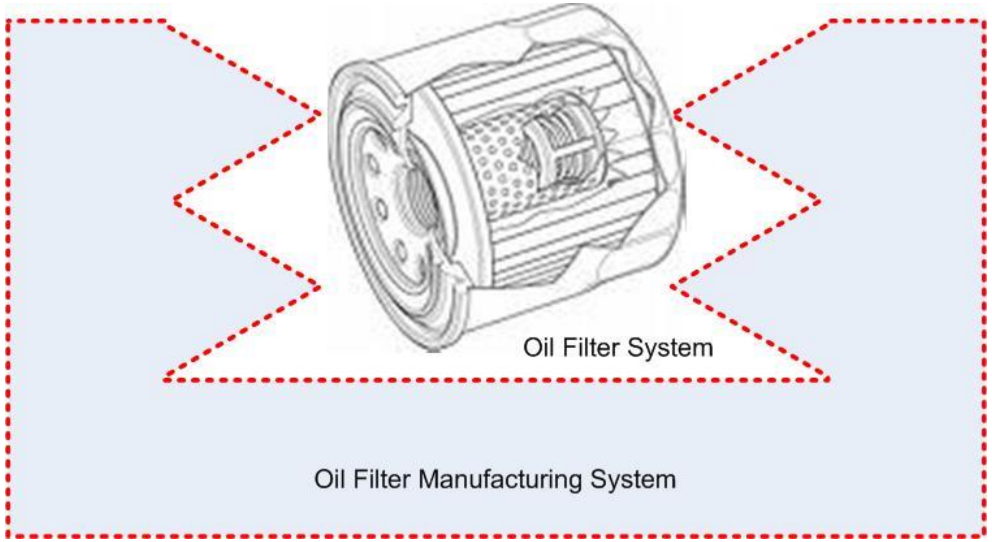
Samples from a simple illustrative example

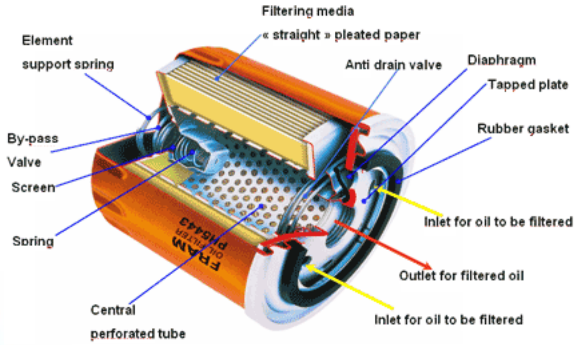


- Product: Oil Filter
- Manufacturing System: Oil Filter Mfg System

Physical Architecture Models describes the physical portion of the technology, to which Functional Roles will later be allocated and optimized . . .

Product Physical Architecture

Architecture 1: Laminated and Accordion Pleated Filtration Media, Flow Orthogonal to Plane of Media, Additive Impregnated

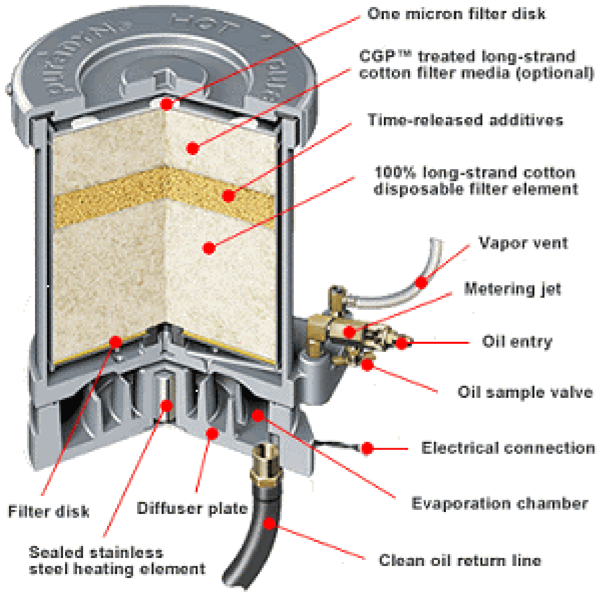


Paper Filter Media

Synthetic Filter Media

Stainless Steel Filter Media

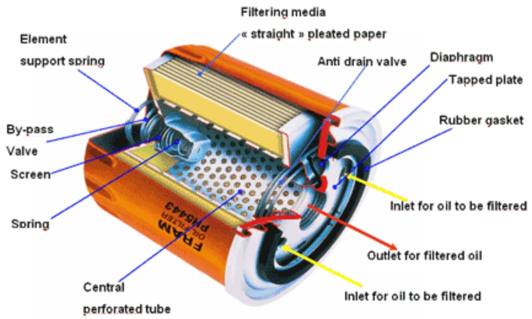
Architecture 2: Wound Filtration Fiber, Flow Orthogonal to Plane of Windings, Additive Impregnated



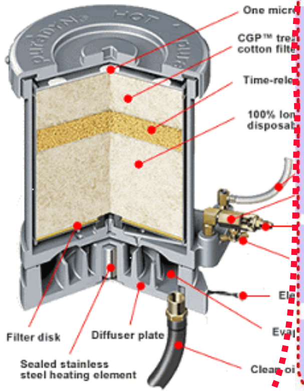
Physical Architecture describes the subject system's major physical components, their organization, and primary physical attributes.

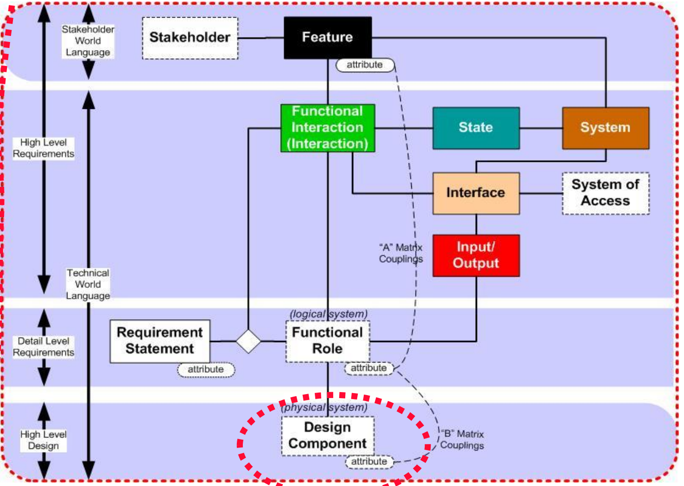
Product Physical Architecture

Architecture 1:



Architecture 2:





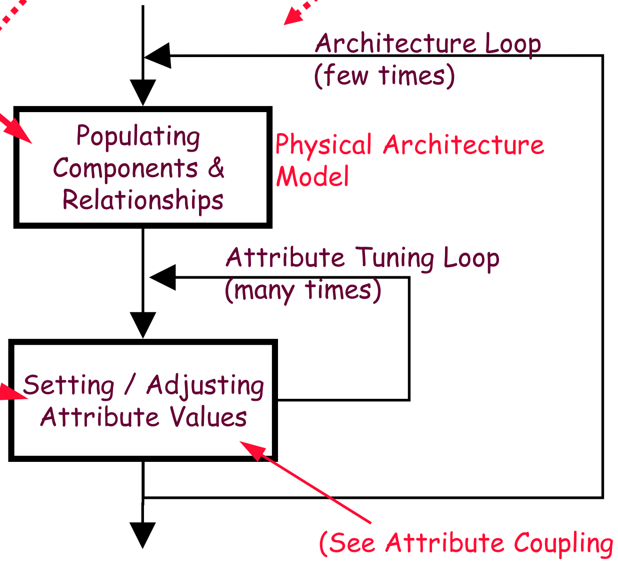
Different architectures

Different attribute values within same architecture

Paper Filter Media

Synthetic Filter Media

Stainless Steel Filter Media



Architecture Loop (few times)

Populating Components & Relationships

Physical Architecture Model

Attribute Tuning Loop (many times)

Setting / Adjusting Attribute Values

(See Attribute Coupling Model)

Directly addressing a key SE challenge: How do we discover <u>all</u> the Requirements, including Manufacturing as well as others?

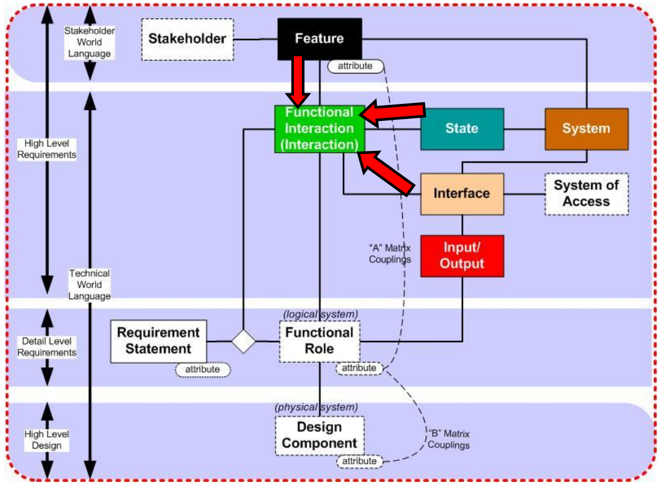
The three MBSE roads to finding all Requirements

MBSE provides a powerful paradigm for discovering <u>all</u> the Interactions, and therefore all the system Functional and Non-Functional Requirements:

1. <u>Domain Model</u>: Find all the external Actors that interact with the system.
2. <u>State Model</u>: Find all the States (situations, modes, phases, use cases) that the system will encounter.
3. <u>Feature Model</u>: Find all the Features valued by Stakeholders.

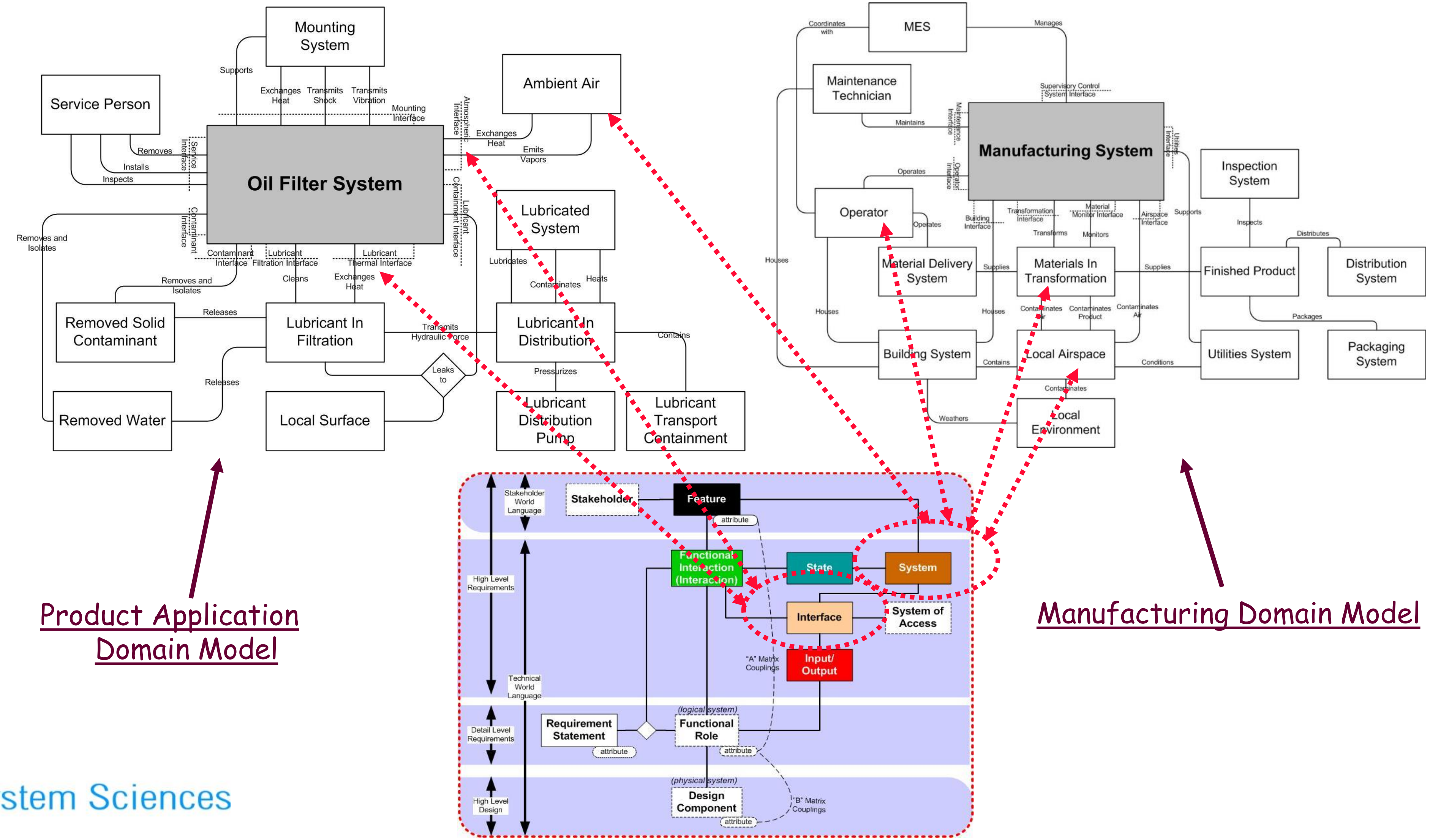
<u>Benefit</u>: These three (<u>redundant</u>) paths provide a higher-than-usual assurance of finding and validating all the Interactions and Requirements.

This is illustrated by the following example Model extracts . . . .



Domain Models directly help by discovering and capturing all the external systems physically interacting with the Subject System—these are the source of all Functional Requirements.

Domain Models

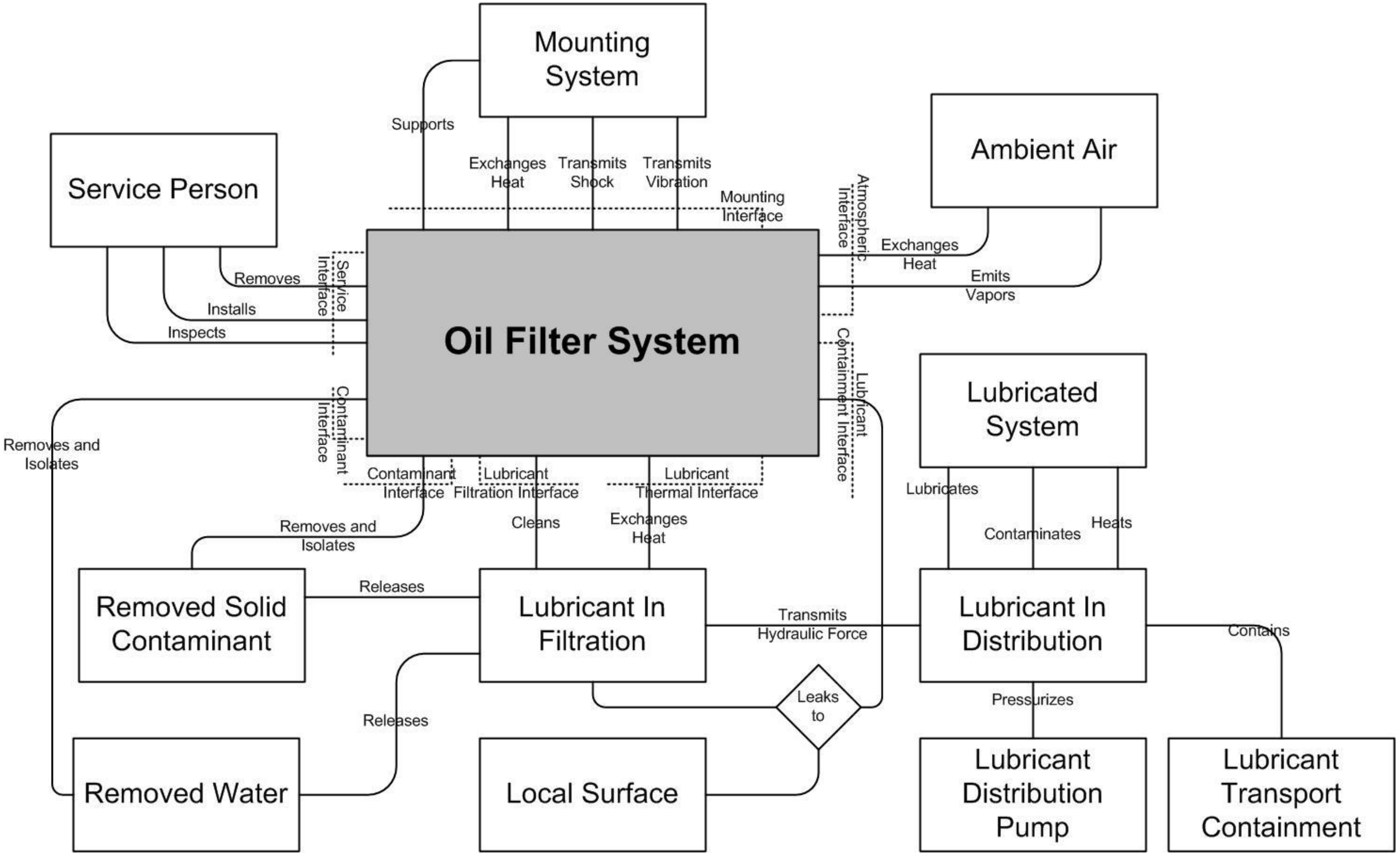


Product Application Domain Model

Manufacturing Domain Model

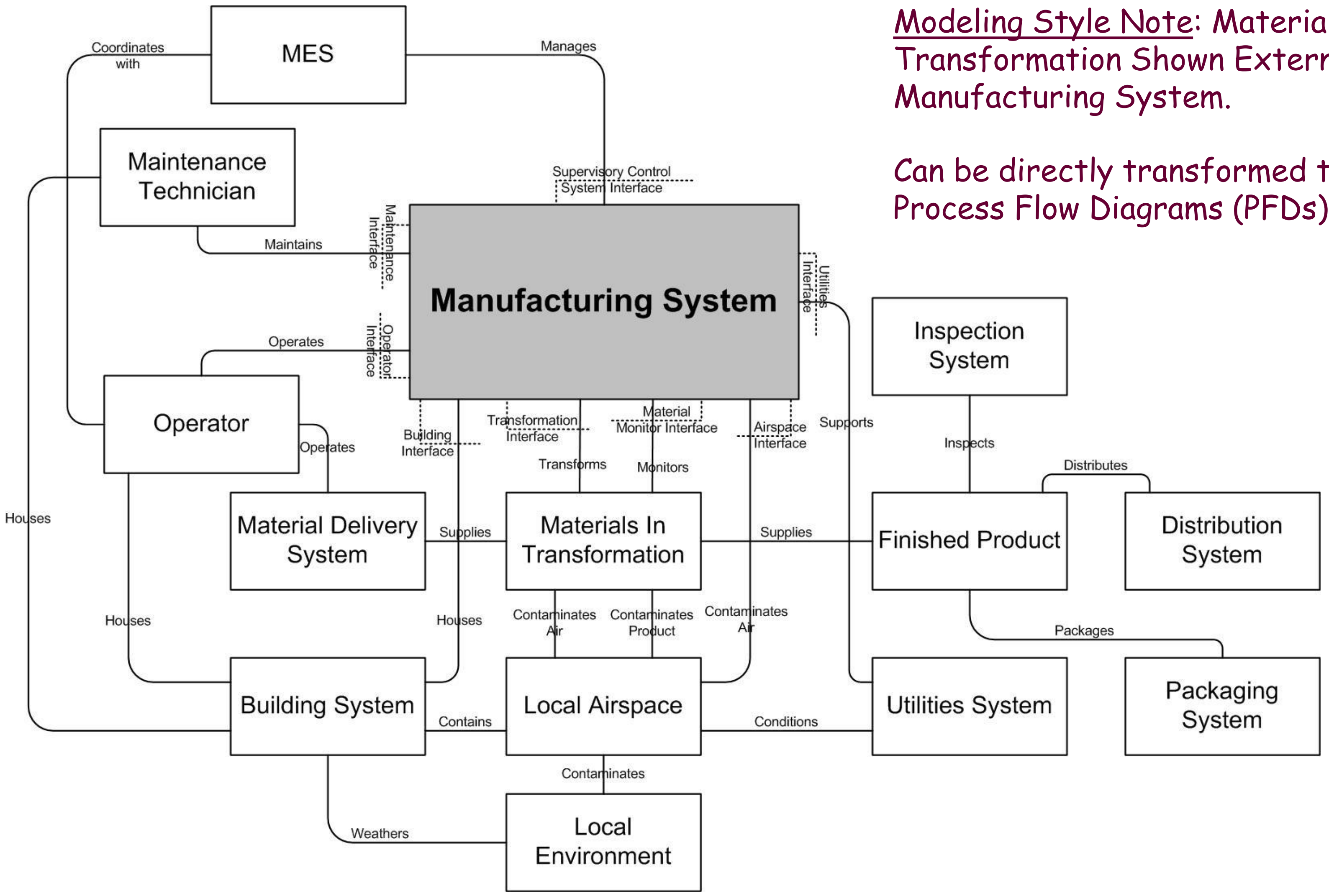
Domain Models show the external systems that interact with a Subject System over its domain life cycle. This defines the System Boundary, External Interfaces, Domain Relationships.

Product Application Domain Model



Domain Models show the external systems that interact with a Subject System over its domain life cycle. This defines the System Boundary, External Interfaces, Domain Relationships.

Manufacturing Domain Model

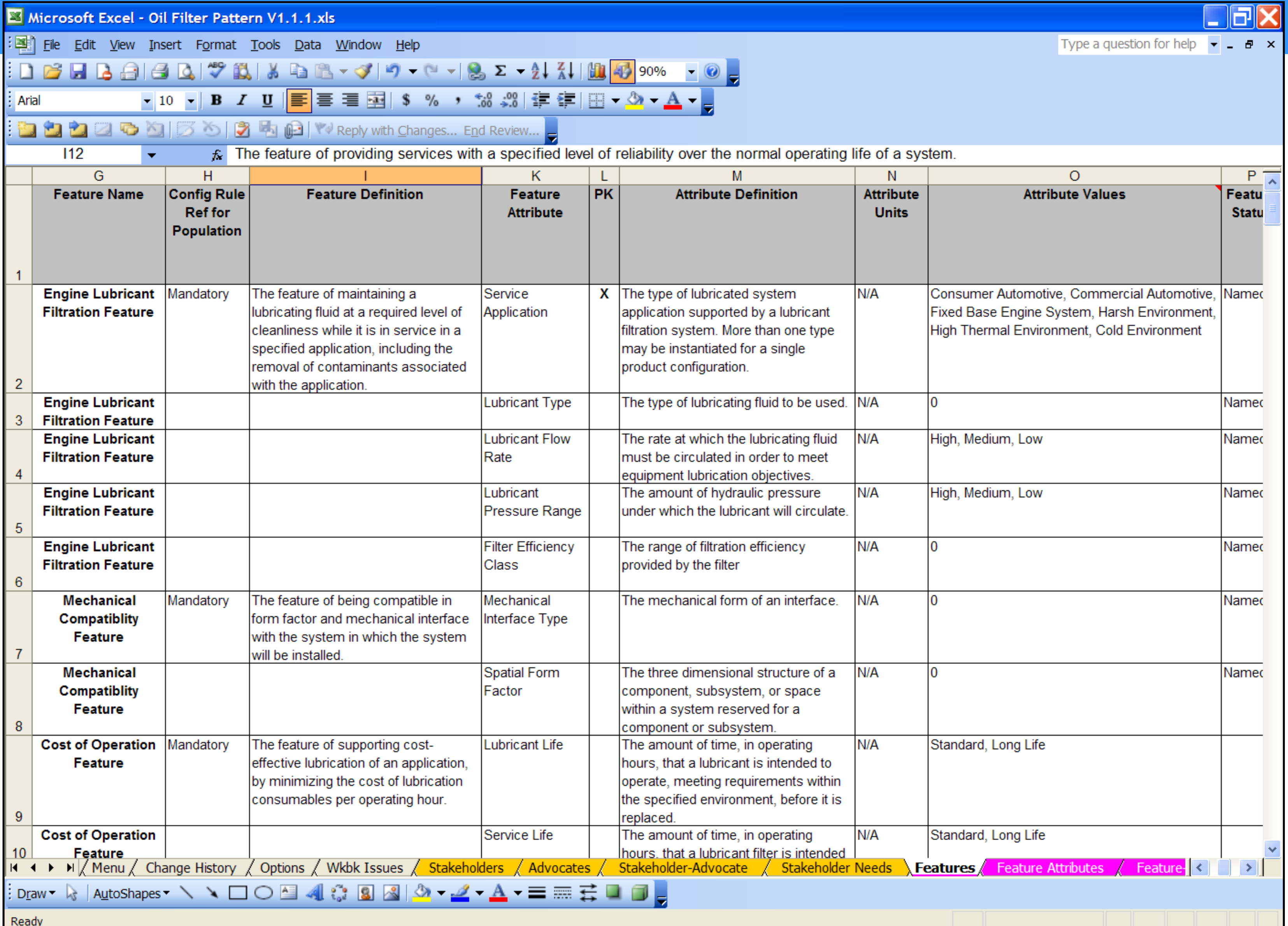


Modeling Style Note: Material In Transformation Shown External to Subject Manufacturing System.

Can be directly transformed to/from Process Flow Diagrams (PFDs).

Stakeholder Feature Models address a key SE challenge by making explicit the ultimate stakeholder outcomes against which all decisions, trade-offs, optimizations, and outcomes will be scored and selected. This covers all Stakeholders, not just Customers (e.g., Shareholders, Community, etc.)

Product Stakeholder Features, Feature Attributes

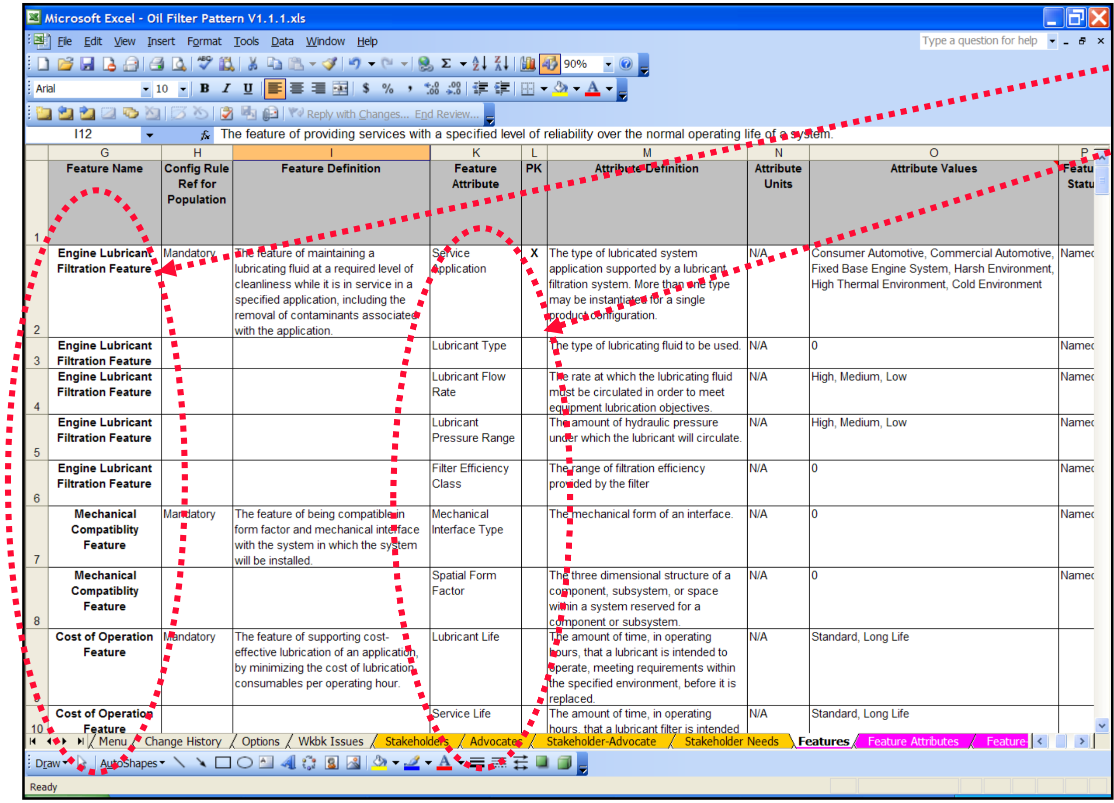


I12 The feature of providing services with a specified level of reliability over the normal operating life of a system.

	G	H	I	K	L	M	N	O	P
1	**Feature Name**	**Config Rule Ref for Population**	**Feature Definition**	**Feature Attribute**	**PK**	**Attribute Definition**	**Attribute Units**	**Attribute Values**	**Featu Statu**
2	**Engine Lubricant Filtration Feature**	Mandatory	The feature of maintaining a lubricating fluid at a required level of cleanliness while it is in service in a specified application, including the removal of contaminants associated with the application.	Service Application	X	The type of lubricated system application supported by a lubricant filtration system. More than one type may be instantiated for a single product configuration.	N/A	Consumer Automotive, Commercial Automotive, Fixed Base Engine System, Harsh Environment, High Thermal Environment, Cold Environment	Name
3	**Engine Lubricant Filtration Feature**			Lubricant Type		The type of lubricating fluid to be used.	N/A	0	Name
4	**Engine Lubricant Filtration Feature**			Lubricant Flow Rate		The rate at which the lubricating fluid must be circulated in order to meet equipment lubrication objectives.	N/A	High, Medium, Low	Name
5	**Engine Lubricant Filtration Feature**			Lubricant Pressure Range		The amount of hydraulic pressure under which the lubricant will circulate.	N/A	High, Medium, Low	Name
6	**Engine Lubricant Filtration Feature**			Filter Efficiency Class		The range of filtration efficiency provided by the filter	N/A	0	Name
7	**Mechanical Compatiblity Feature**	Mandatory	The feature of being compatible in form factor and mechanical interface with the system in which the system will be installed.	Mechanical Interface Type		The mechanical form of an interface.	N/A	0	Name
8	**Mechanical Compatiblity Feature**			Spatial Form Factor		The three dimensional structure of a component, subsystem, or space within a system reserved for a component or subsystem.	N/A	0	Name
9	**Cost of Operation Feature**	Mandatory	The feature of supporting cost-effective lubrication of an application, by minimizing the cost of lubrication consumables per operating hour.	Lubricant Life		The amount of time, in operating hours, that a lubricant is intended to operate, meeting requirements within the specified environment, before it is replaced.	N/A	Standard, Long Life	
10	**Cost of Operation Feature**			Service Life		The amount of time, in operating hours, that a lubricant filter is intended	N/A	Standard, Long Life	

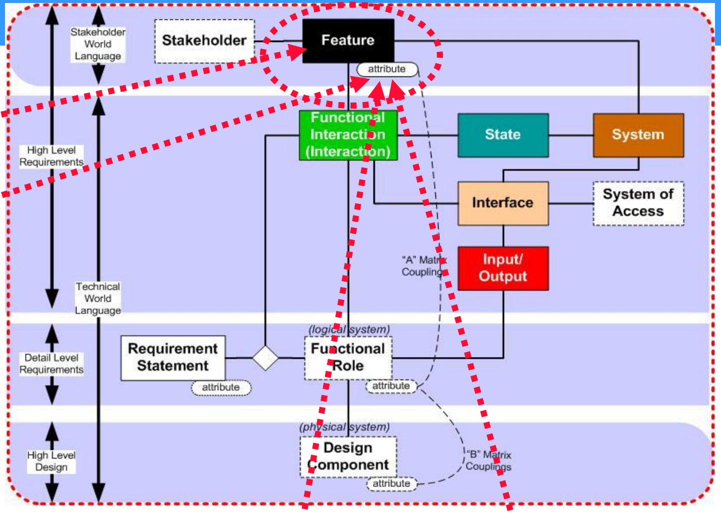
Features are collections of Functional Interactions (behaviors) having value to Stakeholders; their Attributes quantify that value impact. Features are in language of Stakeholders.

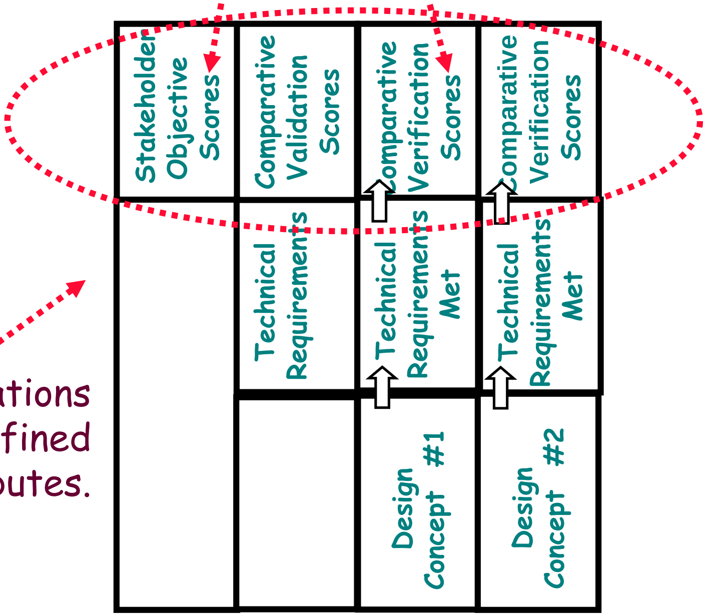
Product Stakeholder Features, Feature Attributes



I12 The feature of providing services with a specified level of reliability over the normal operating life of a system.

	G	H	I	K	L	M	N	O	P
1	Feature Name	Config Rule Ref for Population	Feature Definition	Feature Attribute	PK	Attribute Definition	Attribute Units	Attribute Values	Featu Statu
2	Engine Lubricant Filtration Feature	Mandatory	The feature of maintaining a lubricating fluid at a required level of cleanliness while it is in service in a specified application, including the removal of contaminants associated with the application.	Service Application	X	The type of lubricated system application supported by a lubricant filtration system. More than one type may be instantiated for a single product configuration.	N/A	Consumer Automotive, Commercial Automotive, Fixed Base Engine System, Harsh Environment, High Thermal Environment, Cold Environment	Named
3	Engine Lubricant Filtration Feature			Lubricant Type		The type of lubricating fluid to be used.	N/A	0	Named
4	Engine Lubricant Filtration Feature			Lubricant Flow Rate		The rate at which the lubricating fluid must be circulated in order to meet equipment lubrication objectives.	N/A	High, Medium, Low	Named
5	Engine Lubricant Filtration Feature			Lubricant Pressure Range		The amount of hydraulic pressure under which the lubricant will circulate.	N/A	High, Medium, Low	Named
6	Engine Lubricant Filtration Feature			Filter Efficiency Class		The range of filtration efficiency provided by the filter	N/A	0	Named
7	Mechanical Compatiblity Feature	Mandatory	The feature of being compatible in form factor and mechanical interface with the system in which the system will be installed.	Mechanical Interface Type		The mechanical form of an interface.	N/A	0	Named
8	Mechanical Compatiblity Feature			Spatial Form Factor		The three dimensional structure of a component, subsystem, or space within a system reserved for a component or subsystem.	N/A	0	Named
9	Cost of Operation Feature	Mandatory	The feature of supporting cost-effective lubrication of an application, by minimizing the cost of lubrication consumables per operating hour.	Lubricant Life		The amount of time, in operating hours, that a lubricant is intended to operate, meeting requirements within the specified environment, before it is replaced.	N/A	Standard, Long Life	
10	Cost of Operation Feature			Service Life		The amount of time, in operating hours, that a lubricant filter is intended	N/A	Standard, Long Life	





Configuration Score Sheet

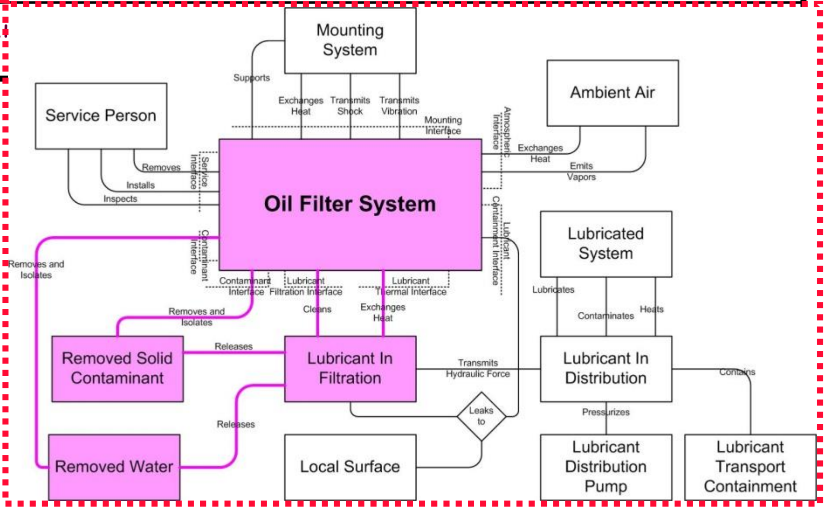
Alternate designs, different configurations, and technology generations are all ultimately "Scored" in lower-dimension trade-off space defined by the Stakeholder Feature Attributes.

For example: Every FMEA (Failure Mode Effects Analysis) failure impact can be expressed in terms of Feature Attributes.

Functional Interaction Models a key SE challenge by discovering and describing all external interactions of a Subject System. This leads to all functional requirements and thereafter all other requirements, in the Detail Requirements Model.

Product Functional Interactions, Roles

Functional Interaction	Functional Roles
Filter Lubricant	Lubricant in Filtration, Oil Filter System, Removed Solid Contaminant, Removed Water
Install Filter	Service Person, Filter
Monitor Filter	Filter, Monitor & Control System
Prevent Vapor Leakage	Lubricant, Vapor, Filter, Atmosphere
Prevent Lubricant Leakage	Lubricant, Filter, Local Surface
Transmit Shock & Vibration	Filter, Mounting System
Transmit Thermal Energy	Filter, Lubricant, Mounting System, Ambient Ai

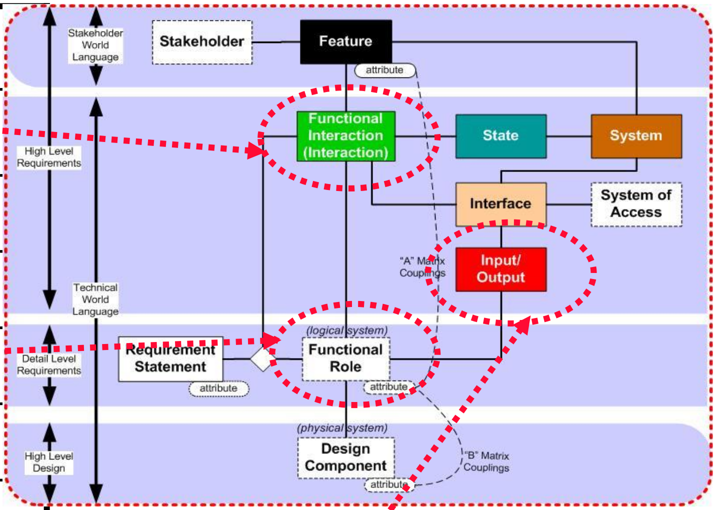


Every system directly interacting with the Subject System (Oil Filter System) contributes to its Requirements.

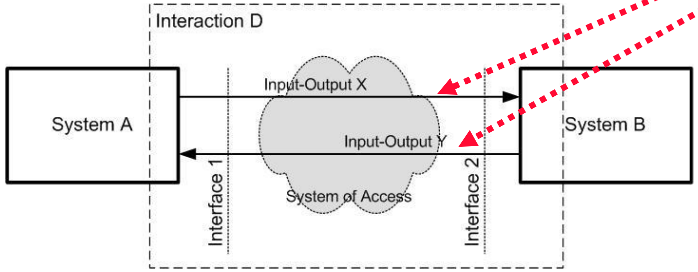
An Interaction of Systems, expressed as an external (outcome) relationship in which systems impact each other's states. Interacting systems fill Roles in the Interaction. Interactions technically characterize (model) the behaviors summarized by stakeholder-valued Features.

Product Functional Interactions, Roles

Functional Interaction	Functional Roles
Filter Lubricant	Lubricant in Filtration, Oil Filter System, Removed Solid Contaminant, Removed Water
Change Filter	Service Person, Filter
Monitor Filter	Filter, Monitor & Control System
Prevent Vapor Leakage	Lubricant, Vapor, Filter, Atmosphere
Prevent Lubricant Leakage	Lubricant, Filter, Local Surface
Transmit Shock & Vibration	Filter, Mounting System
Transmit Thermal Energy	Filter, Lubricant, Mounting System, Ambient Air



Interactions involve two or more systems.



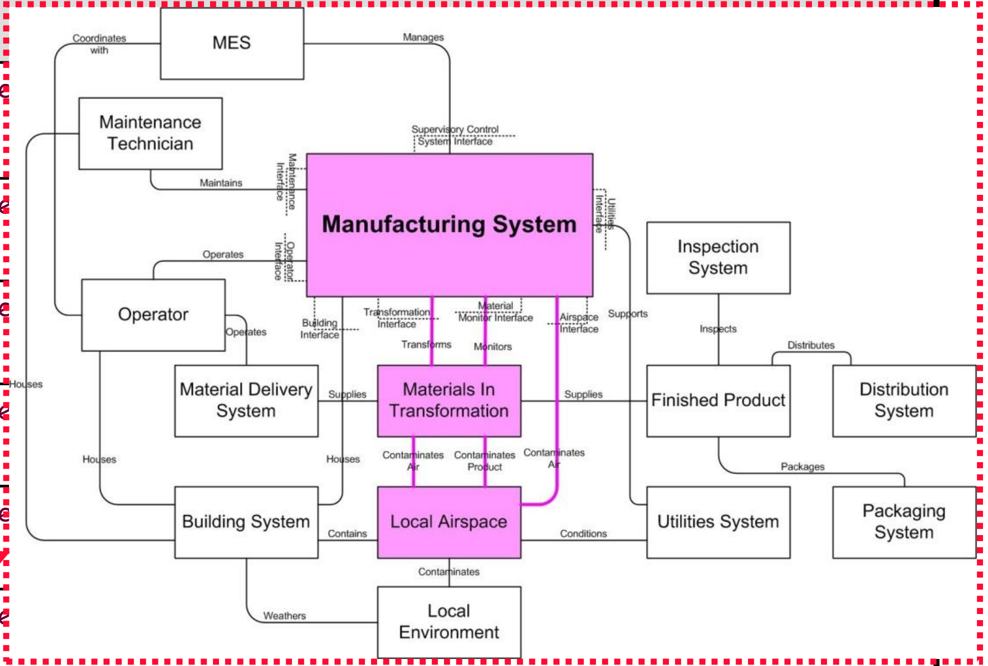
Input/Outputs exchanged during these interactions are:

- Energy
- Force
- Mass
- Information

An Interaction of Systems, expressed as an external (outcome) relationship in which systems impact each other's states. Interacting systems fill Roles in the Interaction. Interactions technically characterize (model) the behaviors summarized by stakeholder-valued Features.

Manufacturing Functional Interactions

Functional Interaction	Functional Roles
Impregnate Lubricant Additive	Manufacturing Syste
Fold Accordion Pleats	Manufacturing Syste
Cut & Separate Filter	Manufacturing Syste
Roll Filter Element	Manufacturing Syste
Wind Filter Element	Manufacturing Syste
Insert Filter Element	Manufacturing Syste
Perform End Seal Bonding	Manufacturing System, Materials In Transformation, Local Airspace

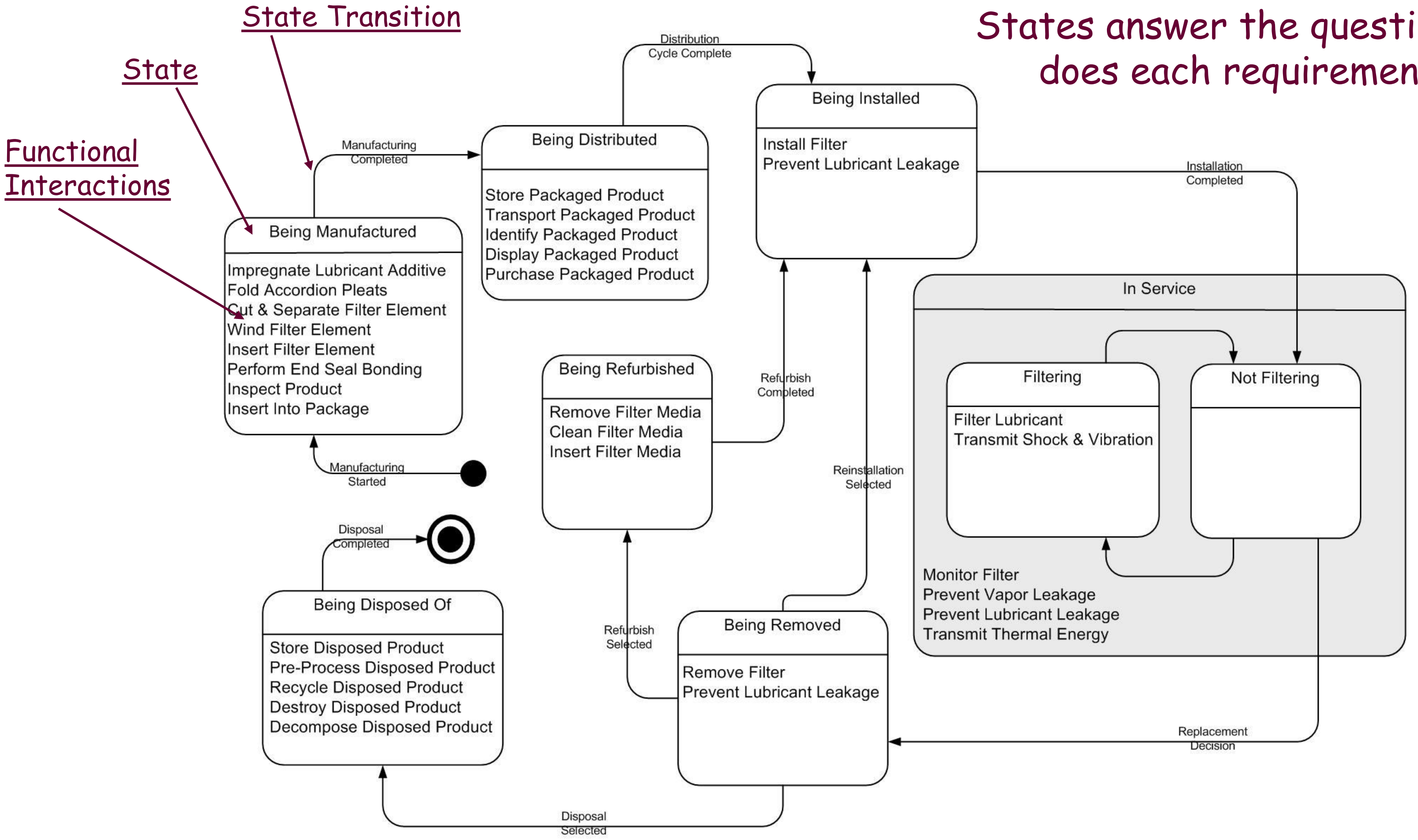


Later "drilled down" in Detail Level Requirements Model, to obtain Requirements Statements.

State Models directly address a key SE challenge by discovering and describing all Situations, Modes, or Use Cases (environmental states) that a Subject System will encounter. These are associated with Functional Interactions that lead directly to requirements. State Models can also describe Designs.

Product State Model

States answer the question: "When does each requirement apply?"



Being Manufactured
Impregnate Lubricant Additive
Fold Accordion Pleats
Cut & Separate Filter Element
Wind Filter Element
Insert Filter Element
Perform End Seal Bonding
Inspect Product
Insert Into Package

Being Distributed
Store Packaged Product
Transport Packaged Product
Identify Packaged Product
Display Packaged Product
Purchase Packaged Product

Being Installed
Install Filter
Prevent Lubricant Leakage

In Service

Filtering
Filter Lubricant
Transmit Shock & Vibration

Not Filtering

Monitor Filter
Prevent Vapor Leakage
Prevent Lubricant Leakage
Transmit Thermal Energy

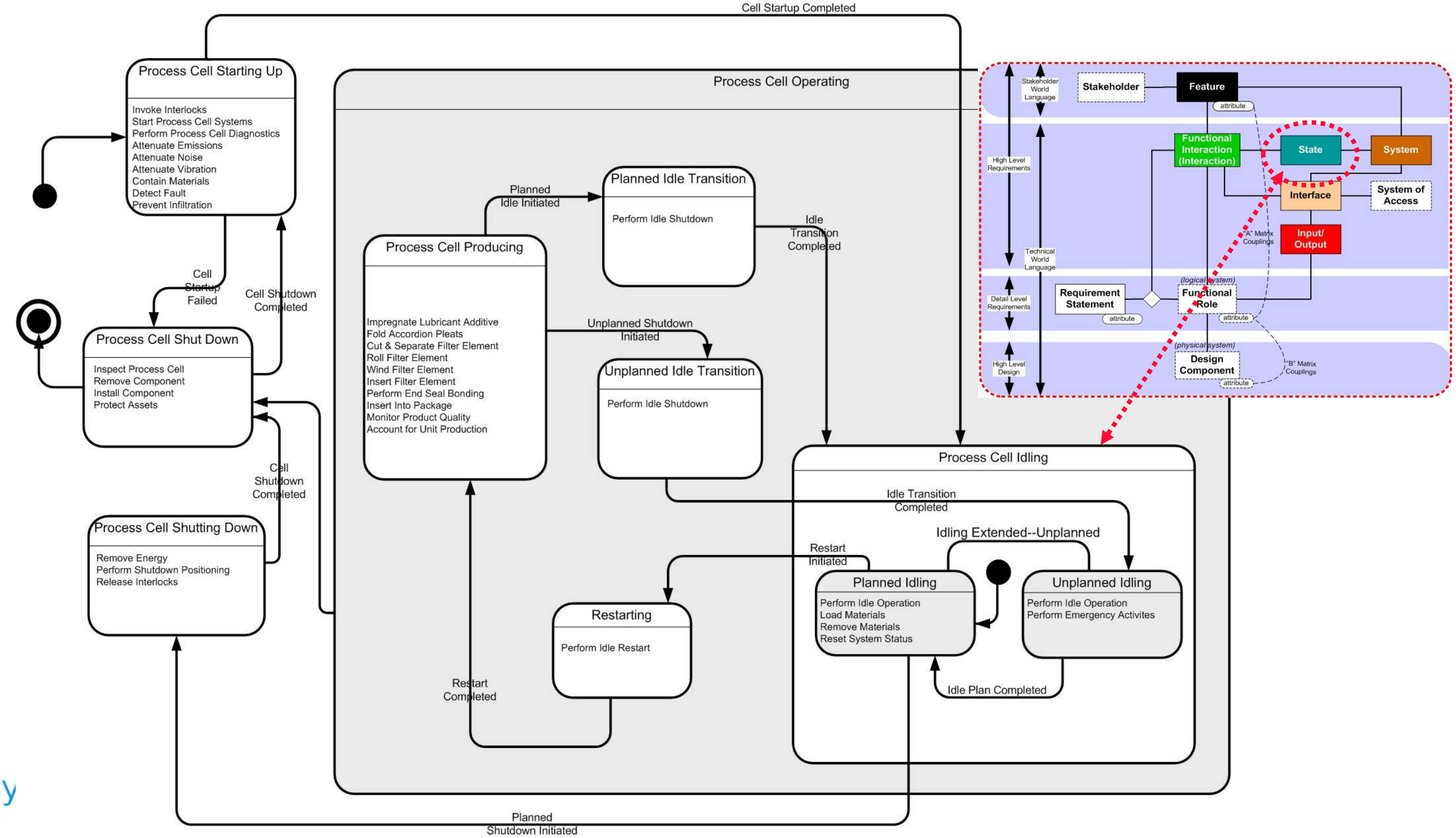
Being Refurbished
Remove Filter Media
Clean Filter Media
Insert Filter Media

Being Removed
Remove Filter
Prevent Lubricant Leakage

Being Disposed Of
Store Disposed Product
Pre-Process Disposed Product
Recycle Disposed Product
Destroy Disposed Product
Decompose Disposed Product

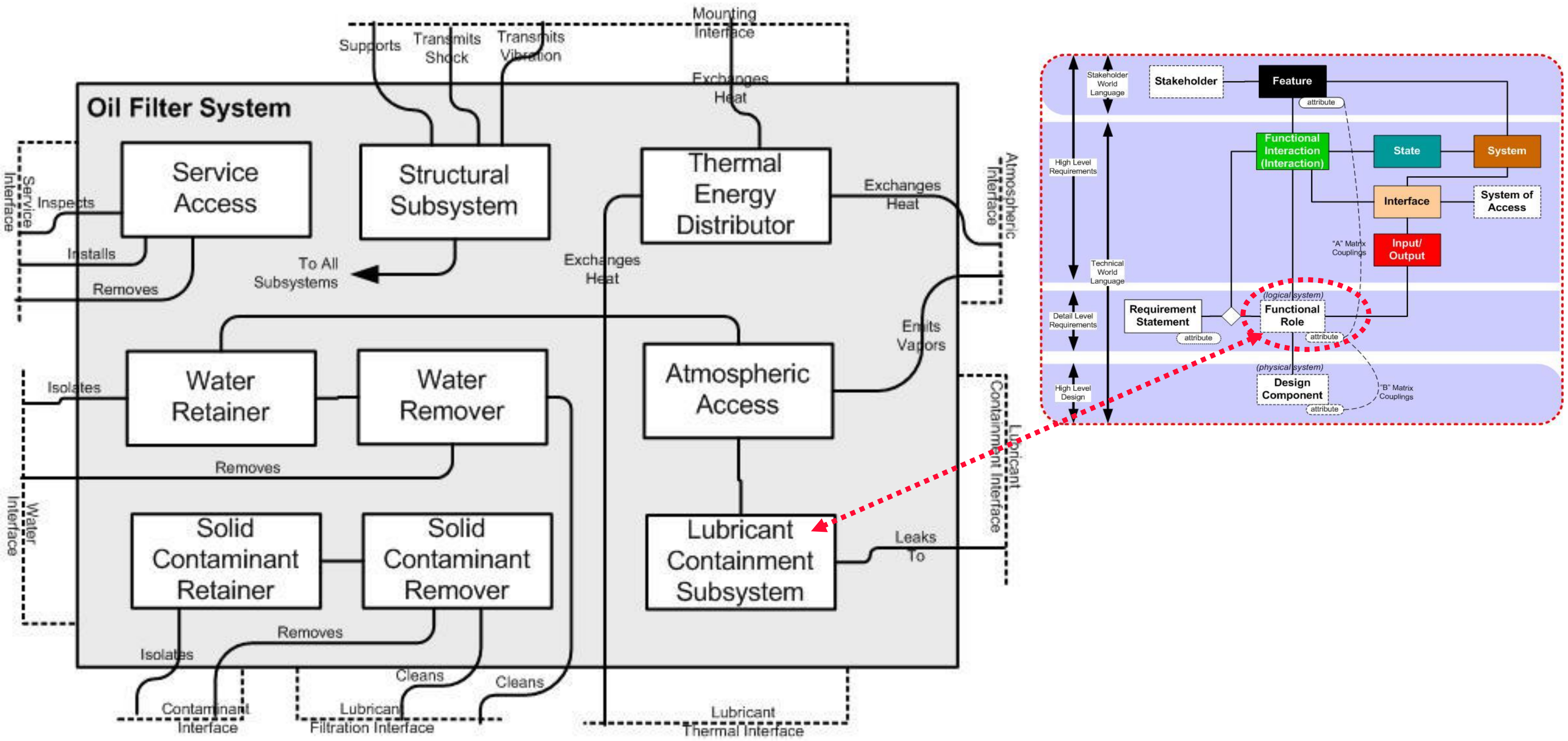
States are Situations (Modes, Use Cases, Phases) that will be encountered in the environment of a Subject System, in which it is required to meet certain requirements.

Manufacturing System State Model



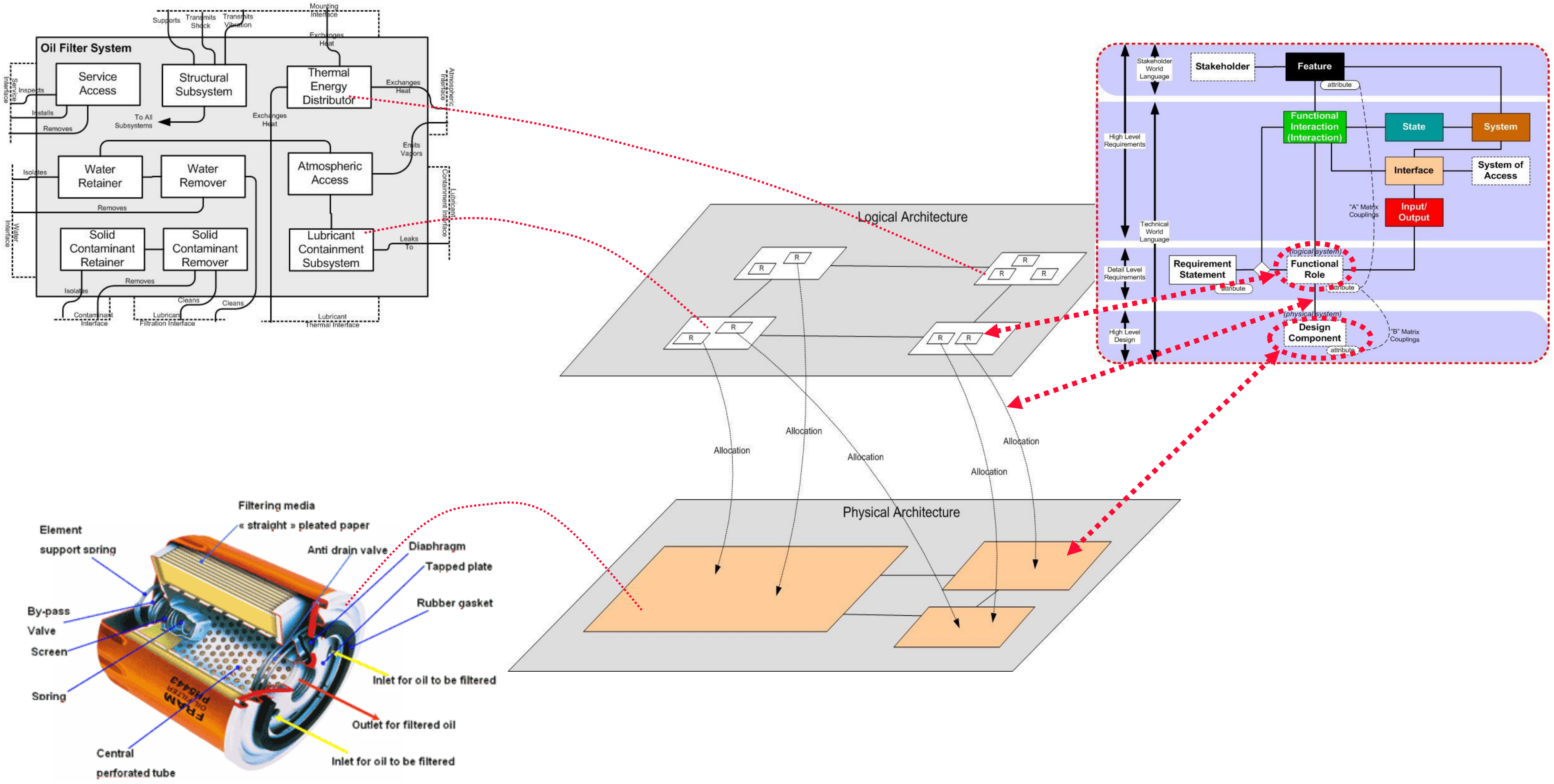
Logical Architecture Models directly address key SE challenges by partitioning the structure of requirements into Logical Roles independent of design, then address more SE challenges by stimulating design ideation and role allocation to physical designs and future technologies.

Product Logical Architecture Model



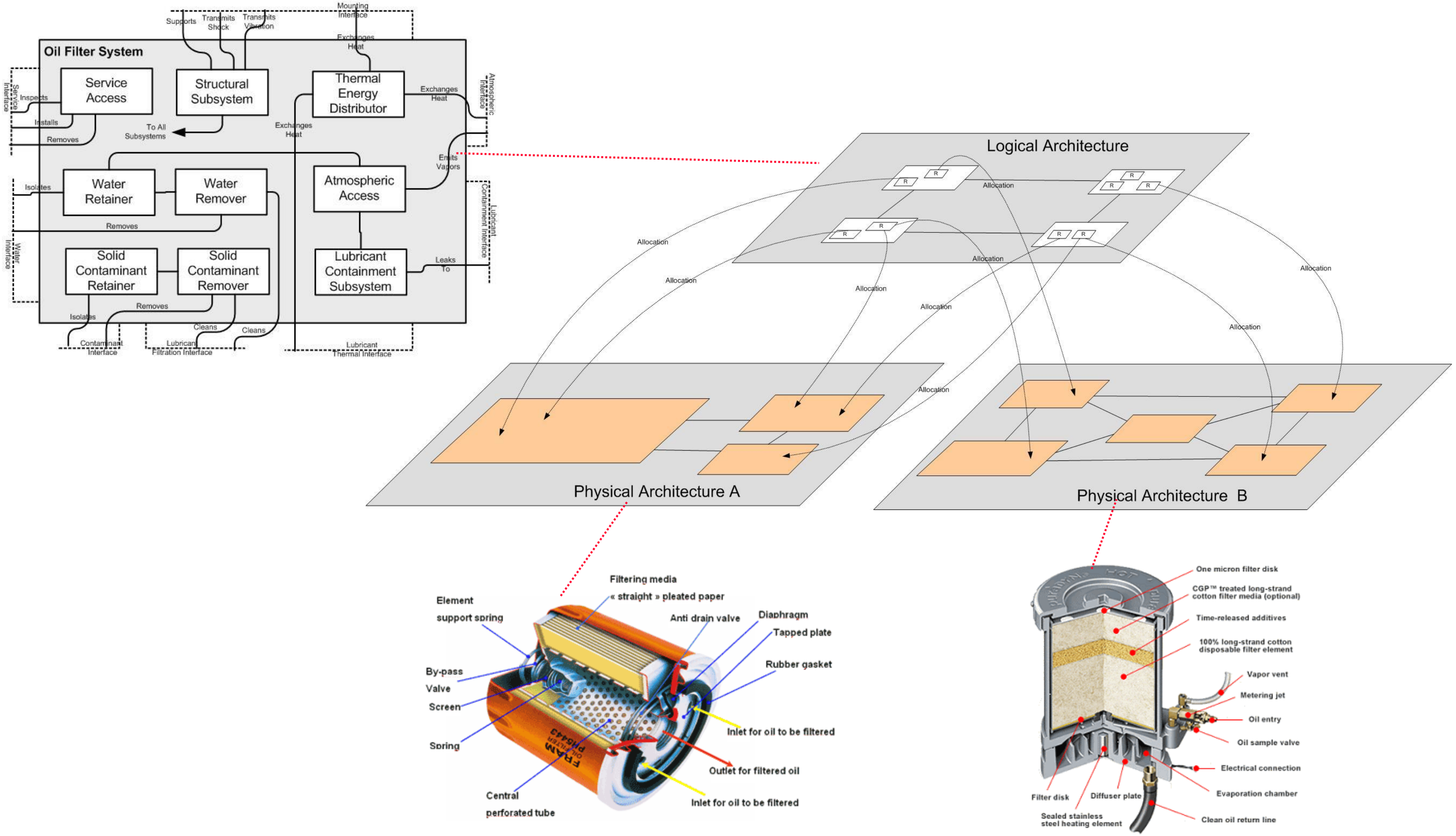
Logical roles are subsets of system behavior that formally model subsystems even though they have not been allocated yet to physical designs.

Allocating Logical Architecture to Physical Architecture



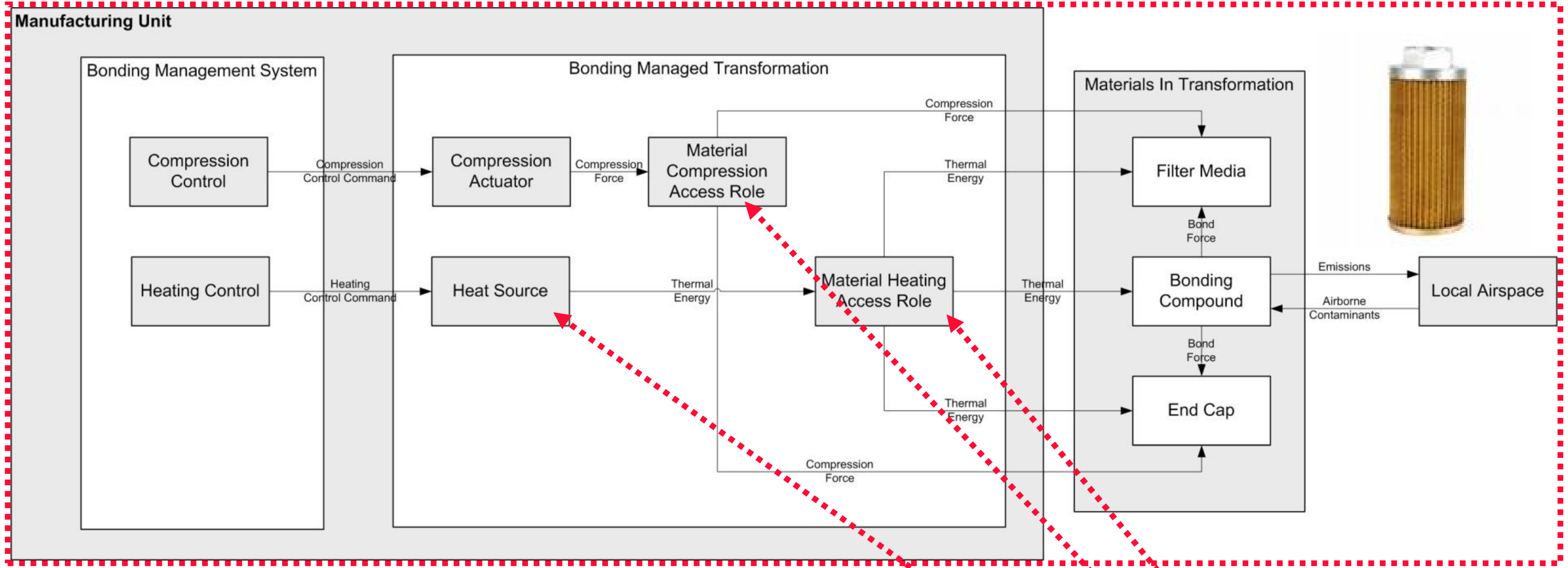
Directly addressing a key SE challenge, multiple alternate physical architectures are typically supported by a single Logical Architecture! This provides a powerful means for managing across Technologies & Configurations, and enhances Platform Management.

Alternate Technologies, Family Configurations, Roadmaps



Detail Interaction Models directly address key SE challenge by providing model-based Requirements. These include Functional as well as non-Functional aspects, including all technical requirements (Role) Attributes.

Detail Interaction Models

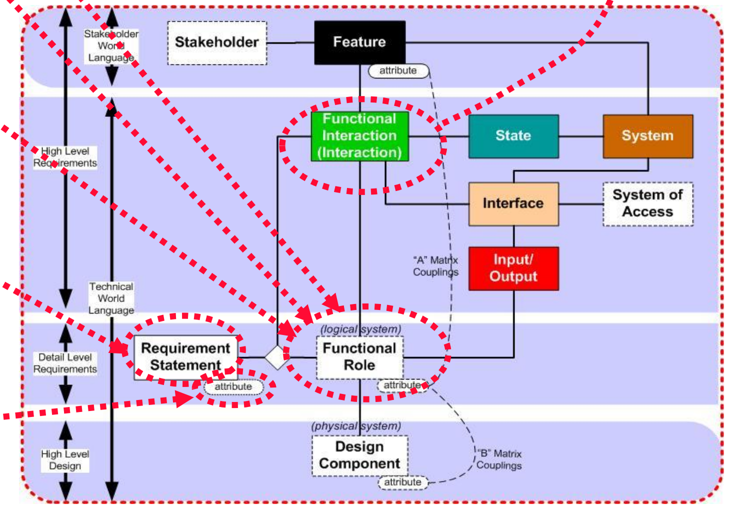


Benefit: This allows prose Requirements Statements to be viewed as Transfer Functions, greatly improving ability to audit regular detail requirements by embedding them in the Model:

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

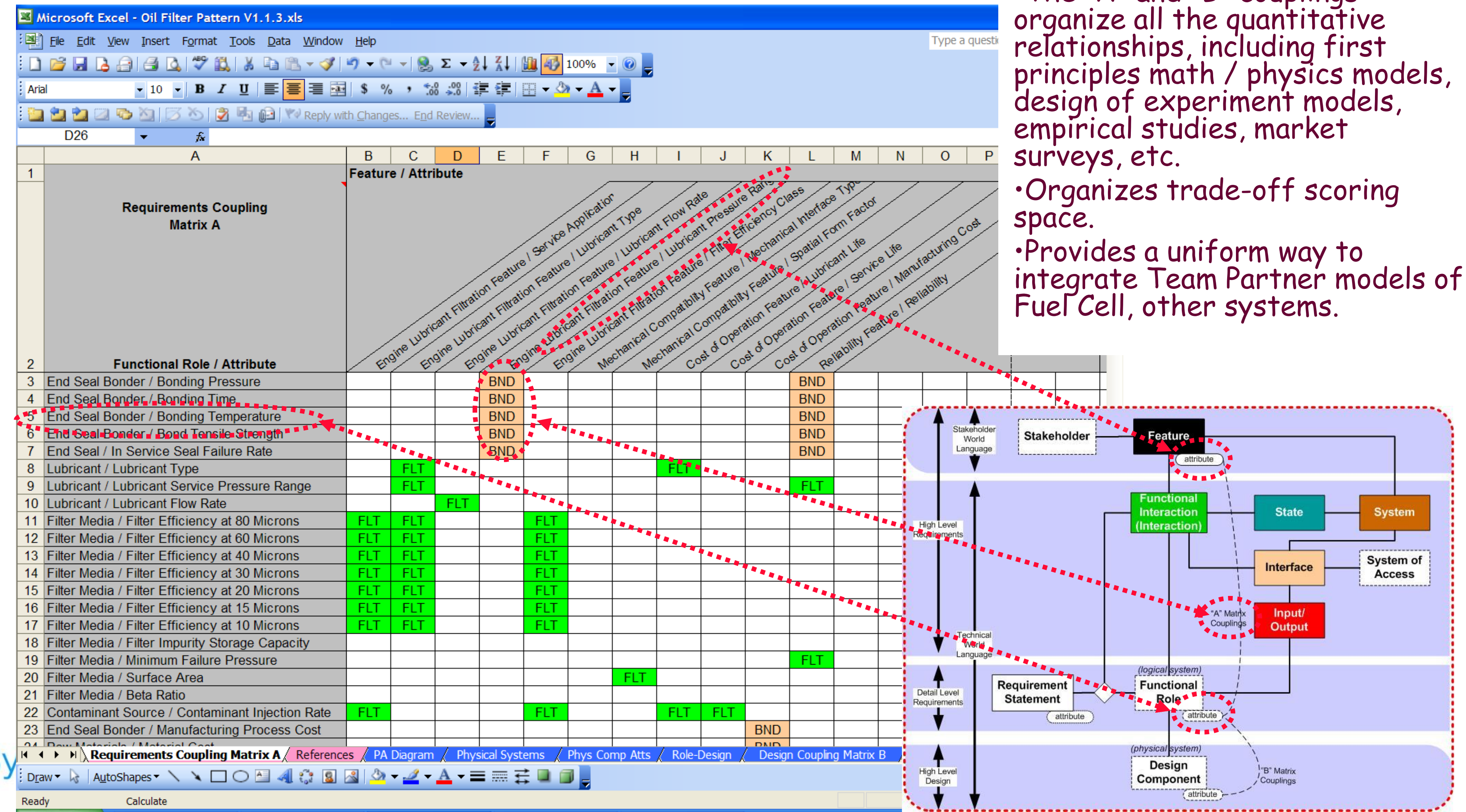
Requirement OFM-33: "The Manufacturing System shall deliver Thermal Energy sufficient to maintain a bond temperature of [Min Bond Temperature] for a period of [Min Bond Time]."

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]."



The Attribute Coupling Model addresses a key SE challenge to understand the quantitative coupling of stakeholder preferences (Features) to technical requirements (Roles), establishing a Feature-based scoring space for trade-offs.

Attribute Coupling Model--Requirements

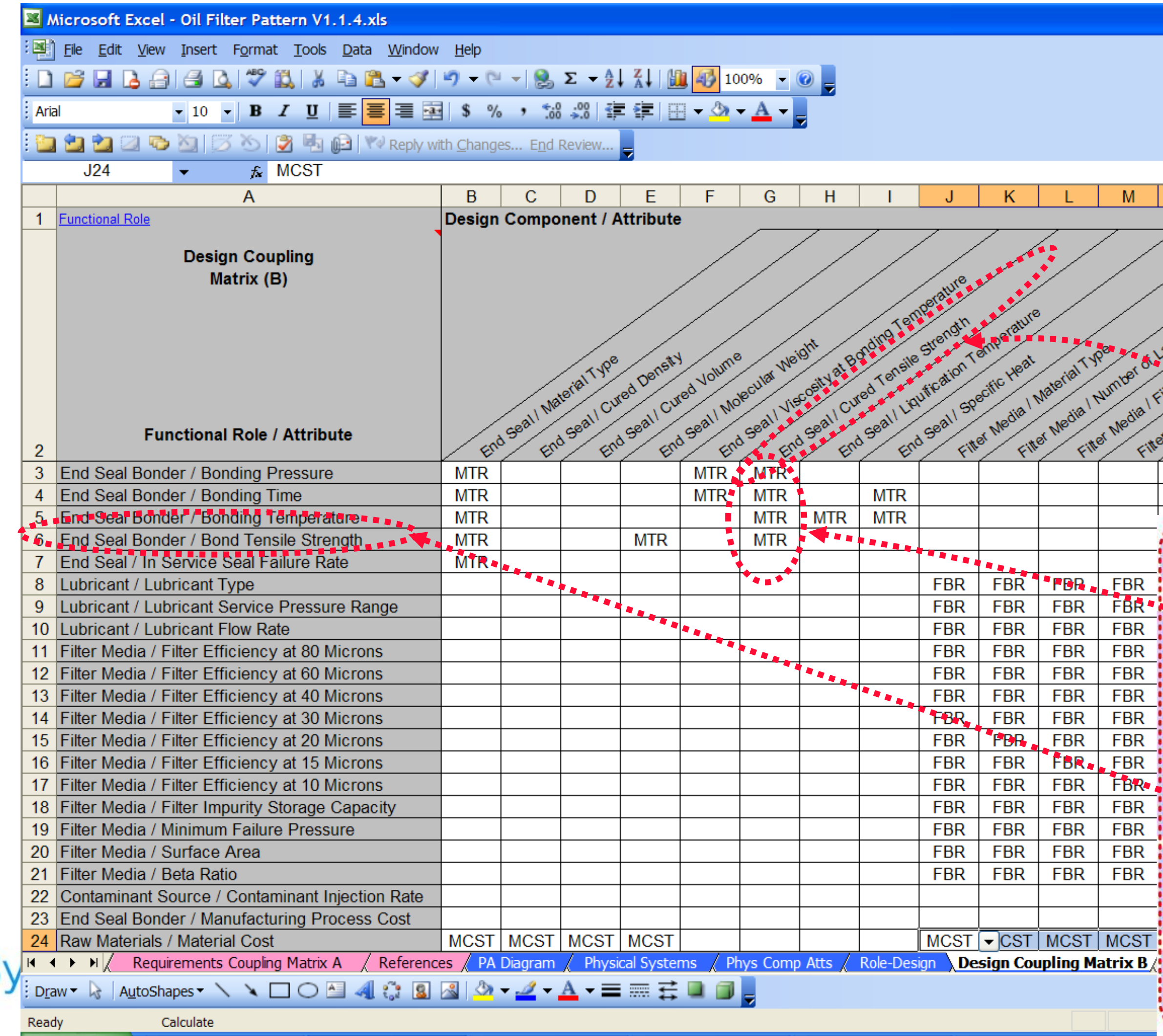


	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P
1	Requirements Coupling Matrix A	Feature / Attribute														
2	Functional Role / Attribute	Engine Lubricant Filtration Feature / Service Application	Engine Lubricant Filtration Feature / Lubricant Type	Engine Lubricant Filtration Feature / Lubricant Flow Rate	Engine Lubricant Filtration Feature / Lubricant Pressure Range	Engine Lubricant Filtration Feature / Filter Efficiency Class	Mechanical Compatibility Feature / Mechanical Interface Type	Mechanical Compatibility Feature / Spatial Form Factor	Cost of Operation Feature / Lubricant Life	Cost of Operation Feature / Service Life	Cost of Operation Feature / Manufacturing Cost	Reliability Feature / Reliability				
3	End Seal Bonder / Bonding Pressure				BND							BND				
4	End Seal Bonder / Bonding Time				BND							BND				
5	End Seal Bonder / Bonding Temperature				BND							BND				
6	End Seal Bonder / Bond Tensile Strength				BND							BND				
7	End Seal / In Service Seal Failure Rate				BND							BND				
8	Lubricant / Lubricant Type		FLT						FLT							
9	Lubricant / Lubricant Service Pressure Range		FLT									FLT				
10	Lubricant / Lubricant Flow Rate			FLT												
11	Filter Media / Filter Efficiency at 80 Microns	FLT	FLT			FLT										
12	Filter Media / Filter Efficiency at 60 Microns	FLT	FLT			FLT										
13	Filter Media / Filter Efficiency at 40 Microns	FLT	FLT			FLT										
14	Filter Media / Filter Efficiency at 30 Microns	FLT	FLT			FLT										
15	Filter Media / Filter Efficiency at 20 Microns	FLT	FLT			FLT										
16	Filter Media / Filter Efficiency at 15 Microns	FLT	FLT			FLT										
17	Filter Media / Filter Efficiency at 10 Microns	FLT	FLT			FLT										
18	Filter Media / Filter Impurity Storage Capacity															
19	Filter Media / Minimum Failure Pressure											FLT				
20	Filter Media / Surface Area							FLT								
21	Filter Media / Beta Ratio															
22	Contaminant Source / Contaminant Injection Rate	FLT				FLT			FLT	FLT						
23	End Seal Bonder / Manufacturing Process Cost										BND					

- The "A" and "B" couplings organize all the quantitative relationships, including first principles math / physics models, design of experiment models, empirical studies, market surveys, etc.
- Organizes trade-off scoring space.
- Provides a uniform way to integrate Team Partner models of Fuel Cell, other systems.

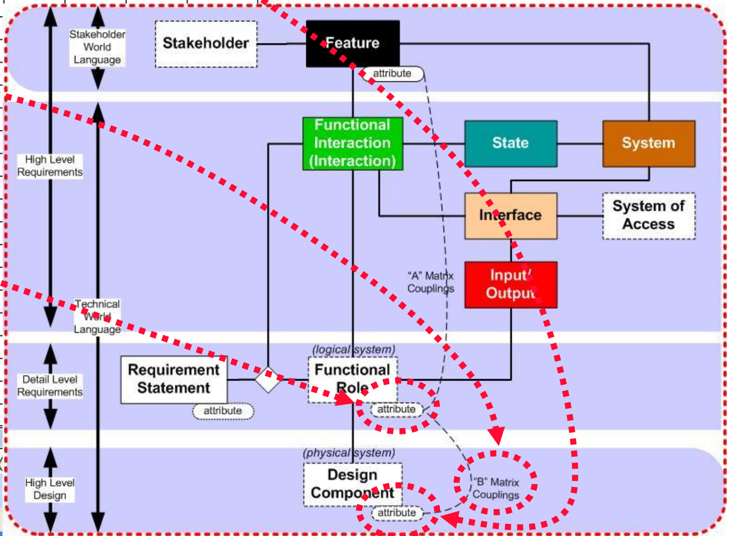
The Attribute Coupling Model addresses a key Challenge to describe the coupling of Design Component attributes to technical requirements (Role) attributes, provide scoring (in Feature Space) of Design Attribute solutions.

Attribute Coupling Model--Designs

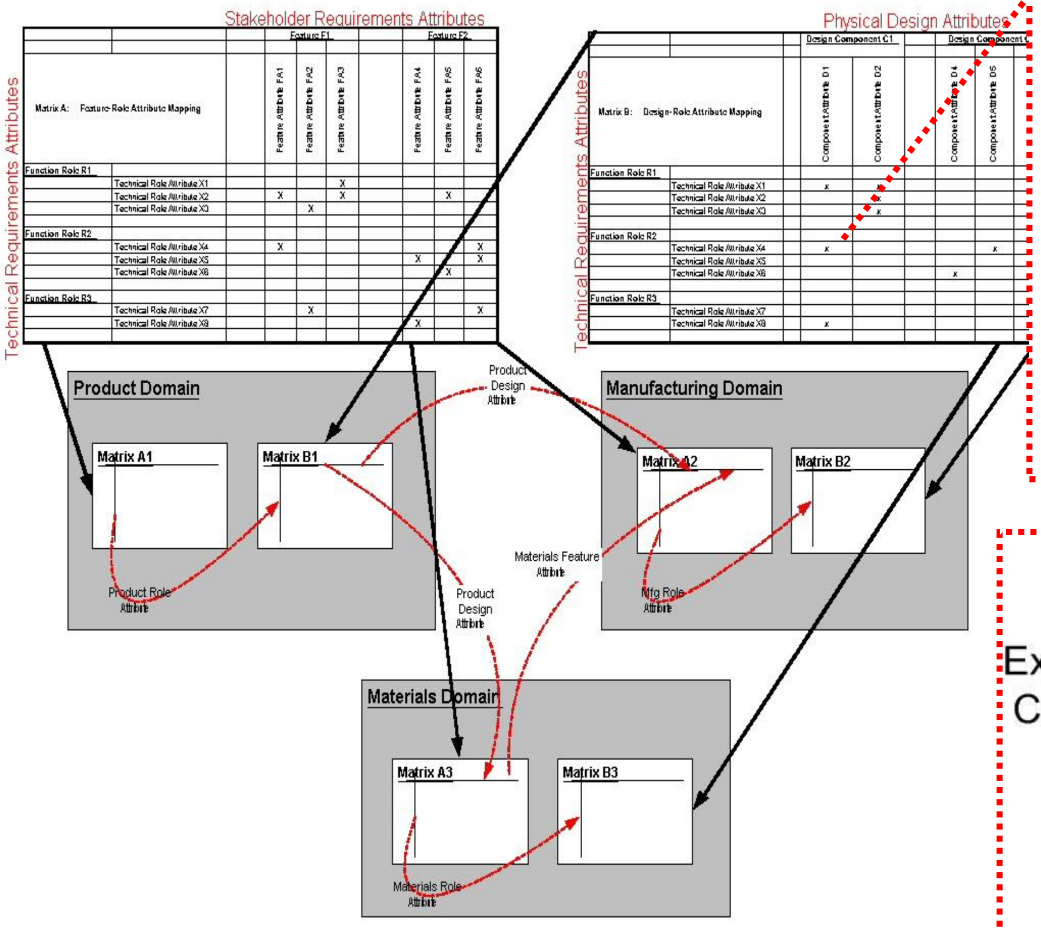


	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O
1	Functional Role	Design Component / Attribute													
2	Design Coupling Matrix (B) Functional Role / Attribute	End Seal / Material Type	End Seal / Cured Density	End Seal / Cured Volume	End Seal / Molecular Weight	End Seal / Viscosity at Bonding Temperature	End Seal / Cured Tensile Strength	End Seal / Liquification Temperature	End Seal / Specific Heat	Filter Media / Material Type	Filter Media / Number of Layers	Filter Media / Fiber Density	Filter Media / Fiber Size	Filter Media / M	End
3	End Seal Bonder / Bonding Pressure	MTR				MTR	MTR								X
4	End Seal Bonder / Bonding Time	MTR				MTR	MTR		MTR						
5	End Seal Bonder / Bonding Temperature	MTR					MTR	MTR	MTR						
6	End Seal Bonder / Bond Tensile Strength	MTR			MTR		MTR								
7	End Seal / In Service Seal Failure Rate	MTR													
8	Lubricant / Lubricant Type									FBR	FBR	FBR	FBR		
9	Lubricant / Lubricant Service Pressure Range									FBR	FBR	FBR	FBR		
10	Lubricant / Lubricant Flow Rate									FBR	FBR	FBR	FBR		
11	Filter Media / Filter Efficiency at 80 Microns									FBR	FBR	FBR	FBR		
12	Filter Media / Filter Efficiency at 60 Microns									FBR	FBR	FBR	FBR		
13	Filter Media / Filter Efficiency at 40 Microns									FBR	FBR	FBR	FBR		
14	Filter Media / Filter Efficiency at 30 Microns									FBR	FBR	FBR	FBR		
15	Filter Media / Filter Efficiency at 20 Microns									FBR	FBR	FBR	FBR		
16	Filter Media / Filter Efficiency at 15 Microns									FBR	FBR	FBR	FBR		
17	Filter Media / Filter Efficiency at 10 Microns									FBR	FBR	FBR	FBR		
18	Filter Media / Filter Impurity Storage Capacity									FBR	FBR	FBR	FBR		
19	Filter Media / Minimum Failure Pressure									FBR	FBR	FBR	FBR		
20	Filter Media / Surface Area									FBR	FBR	FBR	FBR		
21	Filter Media / Beta Ratio									FBR	FBR	FBR	FBR		
22	Contaminant Source / Contaminant Injection Rate														
23	End Seal Bonder / Manufacturing Process Cost														
24	Raw Materials / Material Cost	MCST	MCST	MCST	MCST					MCST	CST	MCST	MCST		

- The "A" and "B" couplings organize all the quantitative relationships, including first principles math / physics models, design of experiment models, empirical studies, market surveys, etc.
- Organizes trade-off scoring space.
- Provides a uniform way to integrate Team Partner models of Fuel Cell, other systems.



Attribute couplings cross domains



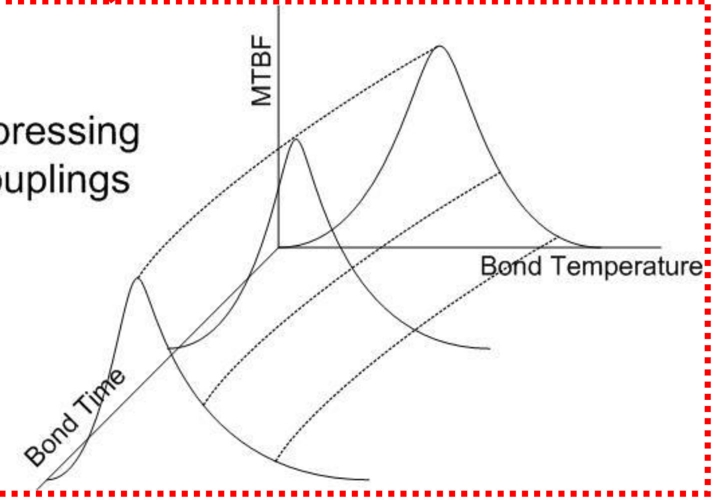
Matrix A: Feature-Role Attribute Mapping		Feature F1			Feature F2		
		Feature Attribute FA1	Feature Attribute FA2	Feature Attribute FA3	Feature Attribute FA4	Feature Attribute FA5	Feature Attribute FA6
Function Role R1							
	Technical Role Attribute X1			X			
	Technical Role Attribute X2	X		X		X	
	Technical Role Attribute X3		X				
Function Role R2							
	Technical Role Attribute X4	X					X
	Technical Role Attribute X5				X		X
	Technical Role Attribute X6					X	
Function Role R3							
	Technical Role Attribute X7		X				X
	Technical Role Attribute X8				X		

Matrix B: Design-Role Attribute Mapping		Design Component C1		Design Component C	
		Component Attribute D1	Component Attribute D2	Component Attribute D4	Component Attribute D5
Function Role R1					
	Technical Role Attribute X1	x	x		
	Technical Role Attribute X2		x		
	Technical Role Attribute X3		x		
Function Role R2					
	Technical Role Attribute X4	x			x
	Technical Role Attribute X5				
	Technical Role Attribute X6			x	
Function Role R3					
	Technical Role Attribute X7				
	Technical Role Attribute X8	x			

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

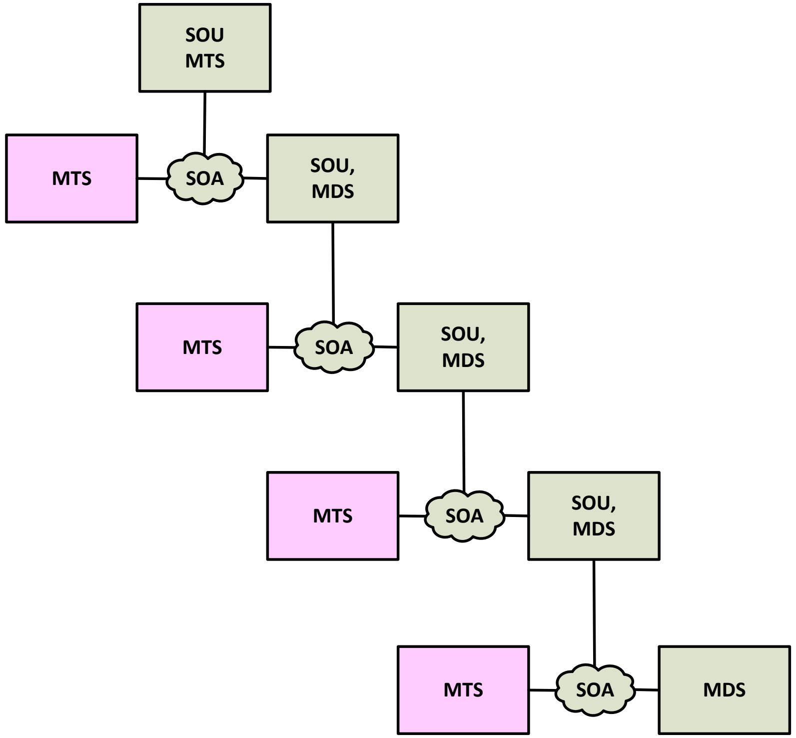
Expressing Couplings



The Embedded Intelligence (EI) S*Pattern

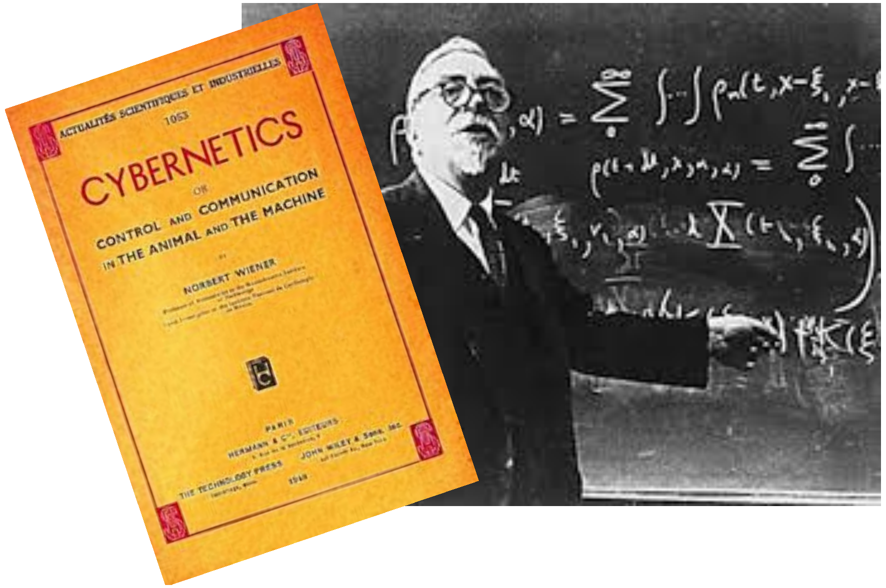
- For any embedding of intelligence, in the form of automation, human operators, or other systems of management, feedback, regulation.

(EI Pattern is currently being exploited in a team paper by GE, ANSYS, FDA, and ICTT authors, about model VVUQ in systems with embedded control.)



Embedded Intelligence (EI) Pattern

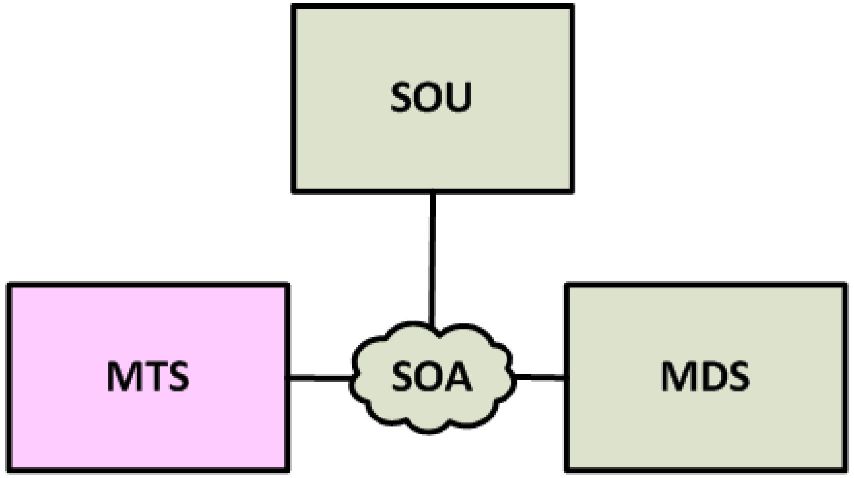
- The EI Pattern returns to the perspective of Norbert Wiener, who first coined the term “cybernetics” to refer to the study of communication and control in living and human-engineered systems:

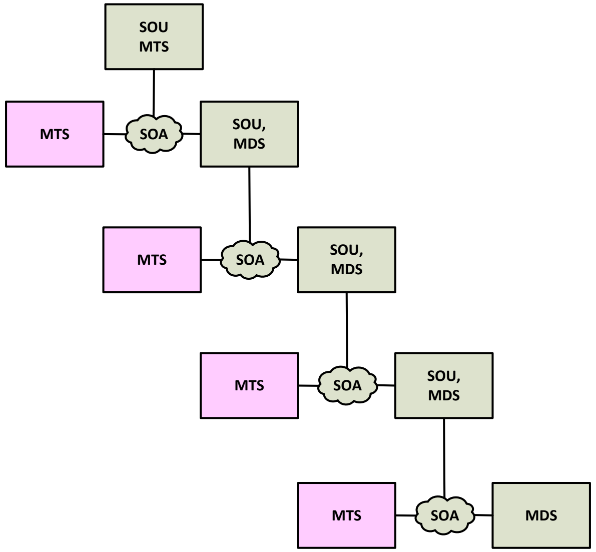


- Especially appropriate if we are interested in Cyber-Physical Systems – but now we are interested in more than just feedback and control performance (studied by Wiener) . . .

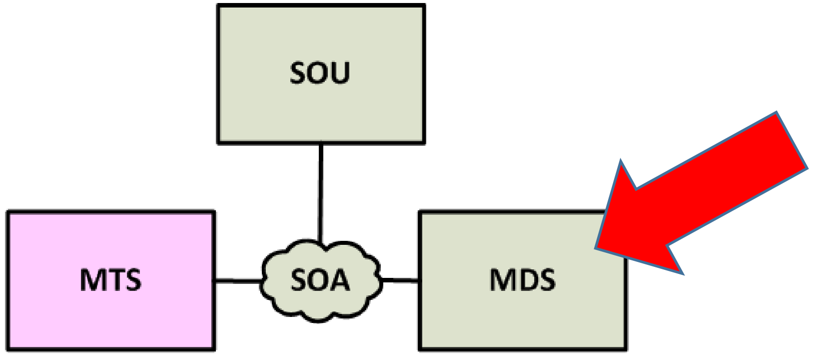
Embedded Intelligence (EI) Pattern

- The EI Pattern is an S*Pattern that emerges to describe intelligence in explicit models of evolving systems in the natural and man-made world:
  - Also referred to as the Management System Pattern.
  - Concerned with the emergence of four roles, emergent at multiple hierarchical levels:



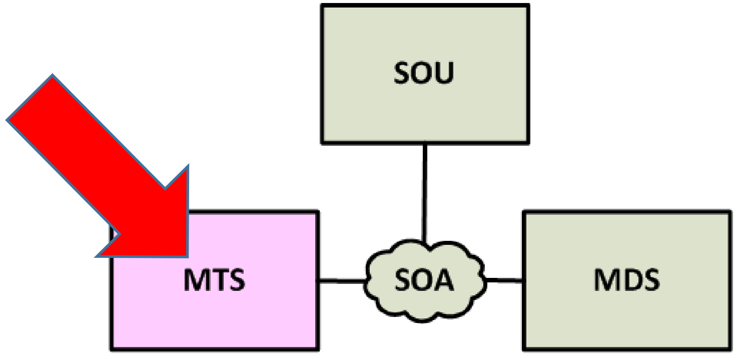


Embedded Intelligence (EI) Pattern



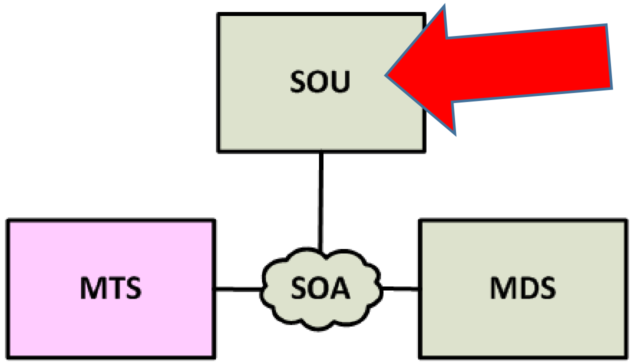
- Managed System (MDS): Any system behavior whose performance, configuration, faults, security, or accounting are to be managed--referred to as System Management Functional Areas (SMFAs) or in ISO terminology fault, configuration, accounting, performance, security (FCAPS).
- These are the roles played by the so-called “physical systems” in a cyber-physical system, providing physical services such as energy conversion, transport, transformation, or otherwise.

Embedded Intelligence (EI) Pattern



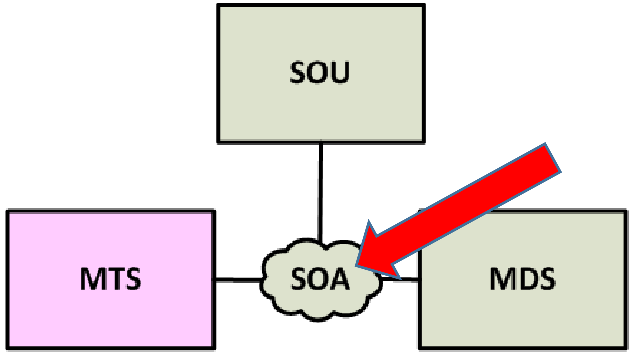
- Management System (MTS): The roles of performing management (active or passive) of any of the SMFAs of the managed system.
- These are so-called “cyber” roles in a cyber-physical system, and may be played by automation technology, human beings, or hybrids thereof, to accomplish regulatory or other management purposes.

Embedded Intelligence (EI) Pattern



- System of Users (SOU): The roles played by a system which consumes the services of an managed system and/or management system, including human system users or other service-consuming systems at higher levels.

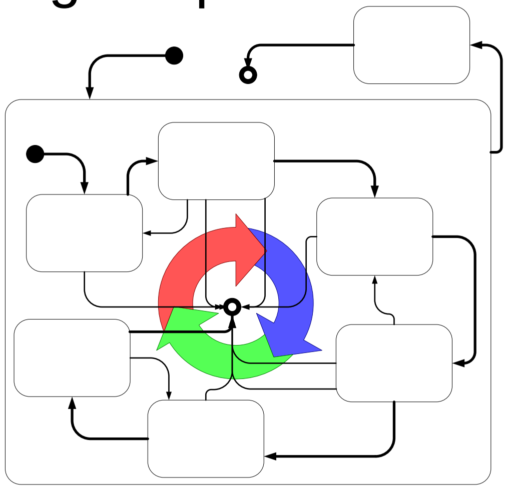
Embedded Intelligence (EI) Pattern



- System of Access (SOA): The roles providing a means of interaction between the other EI roles.
- Engineered sensors, actuators, the Internet, and human-machine interfaces have contributed greatly to the emergence of the “Internet of Things”..

Embedded Intelligence (EI) Pattern

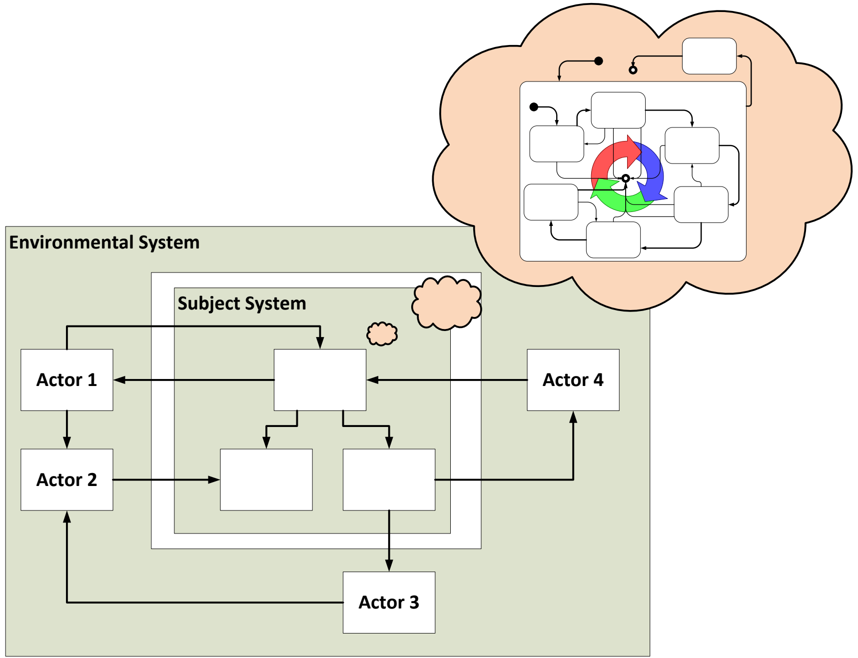
- The State Model portion of the EI Pattern provides insight into the nature of the “regulatory” role of embedded intelligence.
- These show numerous “situation resolution cycles” that drive the managed system to nominal states, when various situations are encountered:
  - Major mission cycles, from mission start to completion
  - Fault resolution cycles, other lesser or minor situation resolution cycles
  - Configuration change cycles, including adaptations
  - Fulfillment of requests for services
  - Security condition resolution cycles
  - Other situation resolution cycles
- Specific or general situations



Sample EI Situation Resolution Cycle

Embedded Intelligence (EI) Pattern

- A system that is capable of not only traversing a situation resolution cycle, but also recognizing that a triggering situation has arisen in the first place is said to be “Situationally Aware”:
  - If a human operator control panel has a “mode switch”, the system relies on the human to be aware of situations, launching the appropriate cycles
  - More advanced systems recognize these situations autonomously—also leading to EI Attention Model recognition of finite system resources.

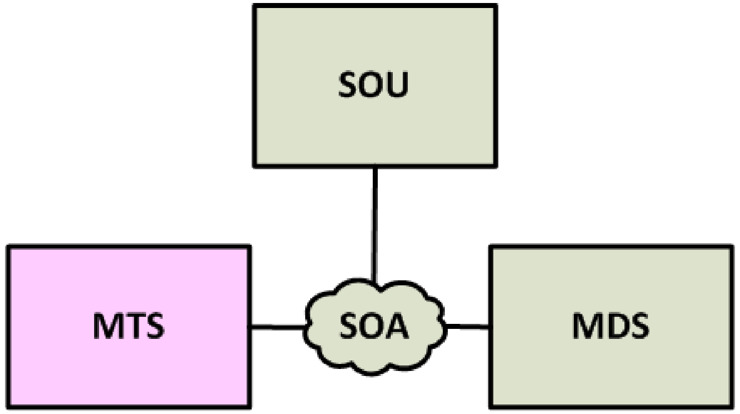


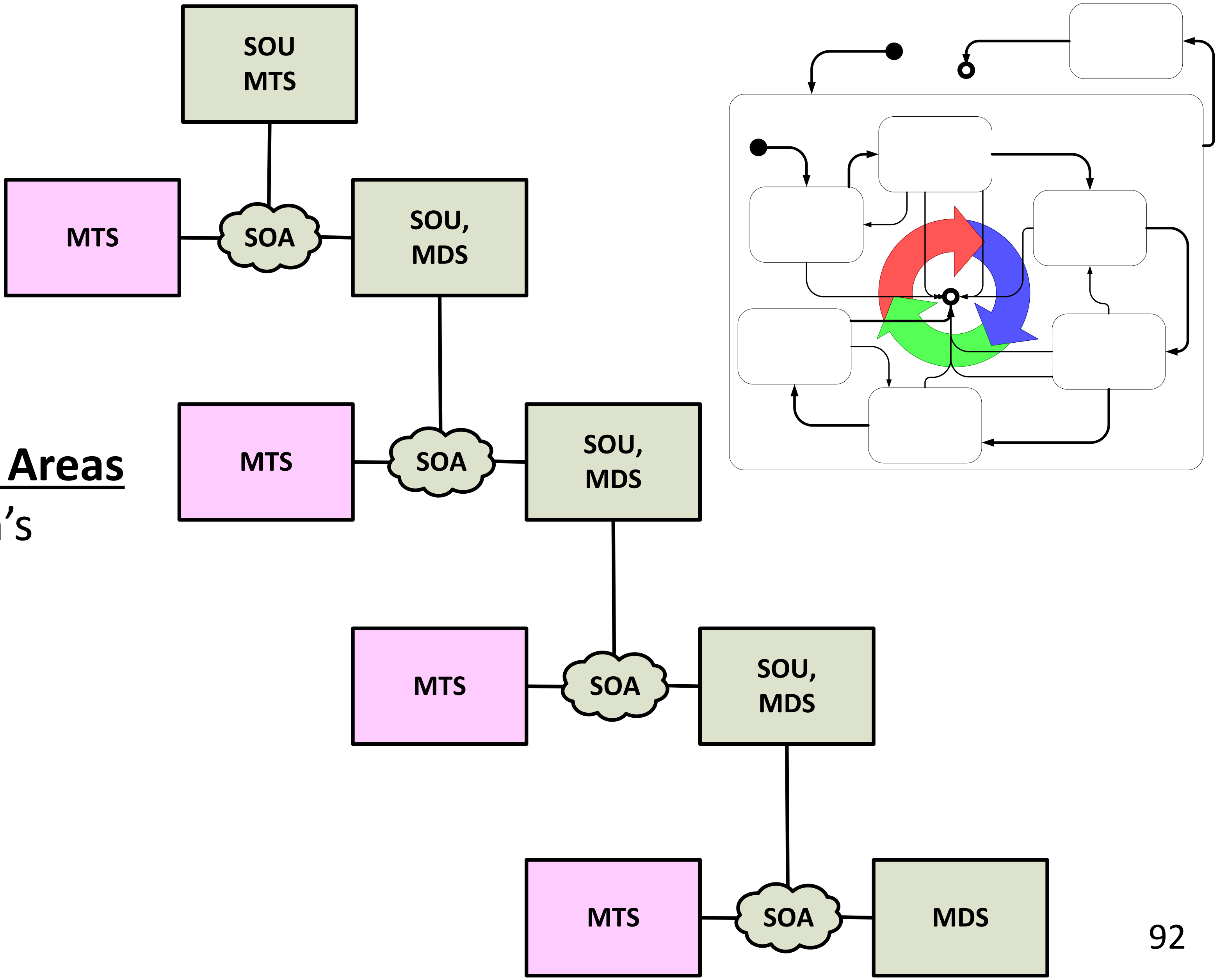
Sample S*Pattern Extracts

From Embedded Intelligence (EI) Pattern (AKA Management Pattern):

- Generic EI Functional Roles and Situation Management States
- Sample EI Stakeholder Features
- Sample EI Interactions
- Sample EI Requirements and Attribute Table References
- General Pattern Configuration Overview

Generic EI Functional Roles, SMFA Situation Management States

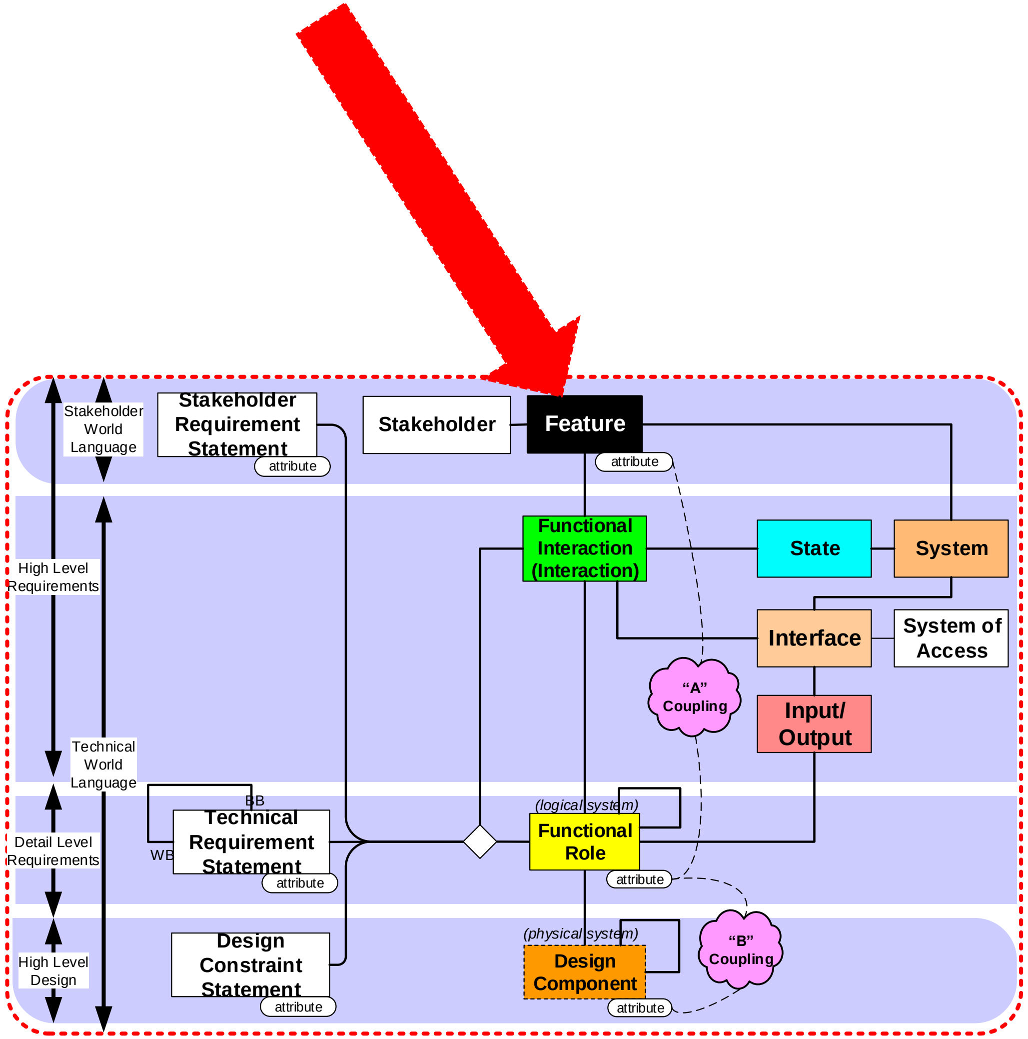




The **<u>System Management Functional Areas (SMFAs)</u>**: Manage aspects of a system's faults, configuration, accounting, performance, or security (FCAPS).

MDS: Managed System
MTS: Management System
SOA: System of Access
SOU: System of Users

Sample EI Stakeholder Features



System Performance Management

Performance Management Capability

System Configuration Management

Configuration Management Capability

System Security Management

Security Management Capability

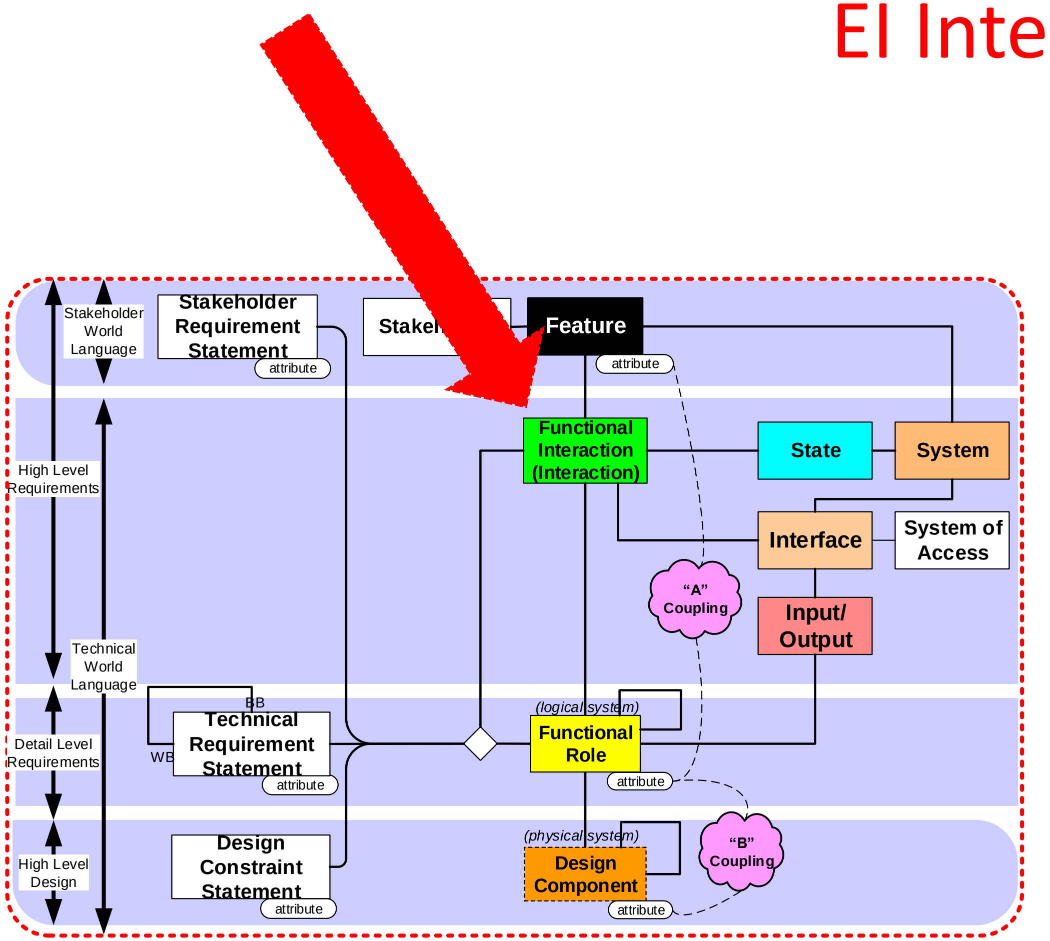
System Accounting Management

Accounting Management Capability

System Fault Management

Fault Management Capability

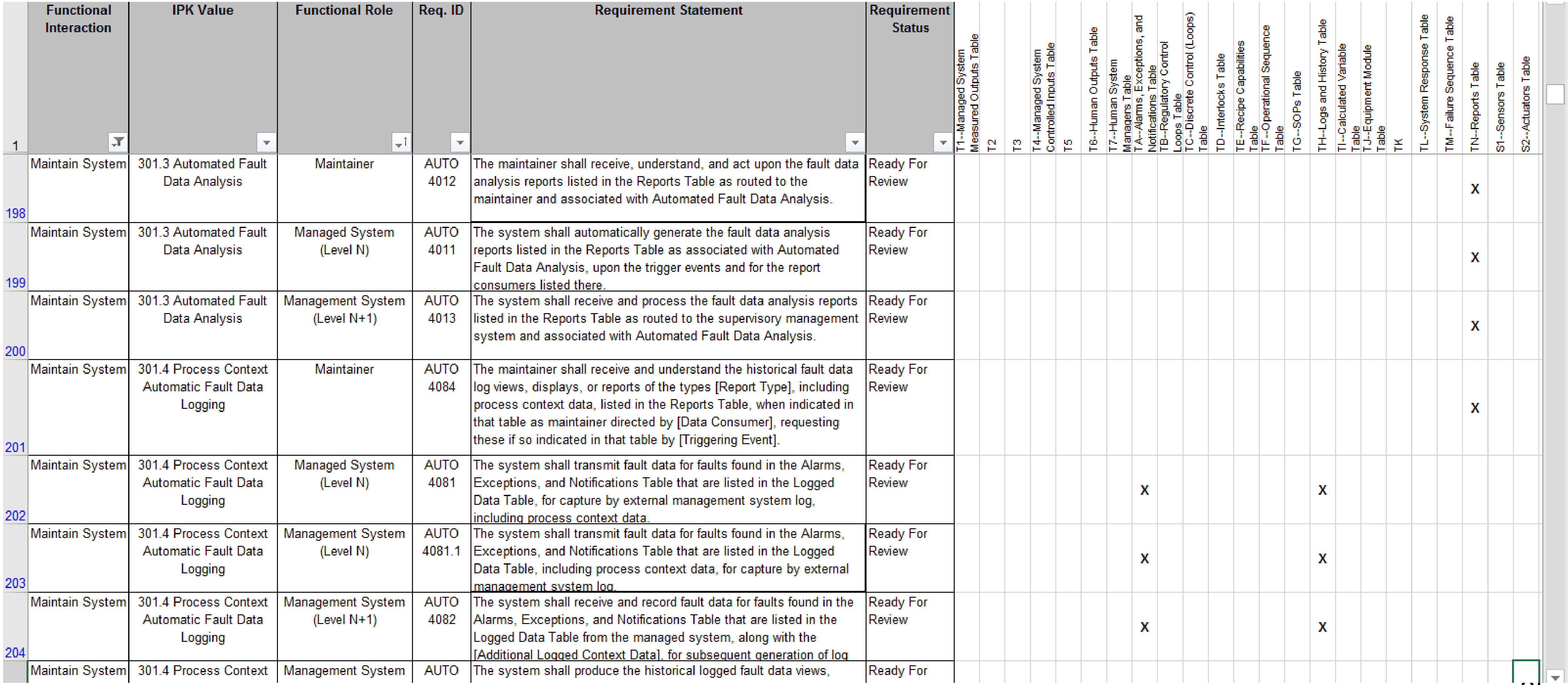
Sample EI Interactions



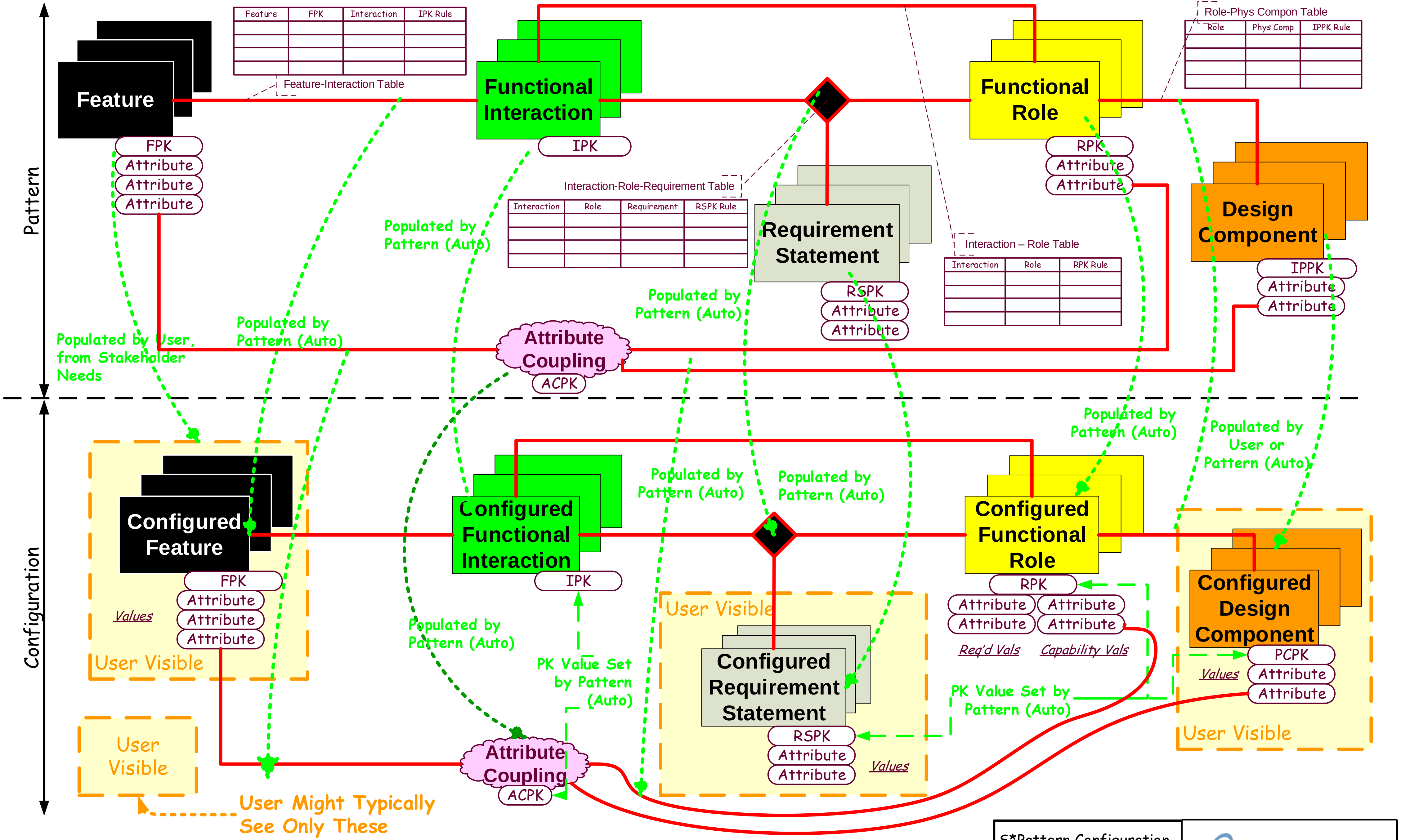
EI Interactions

- Operate System
- Maintain System
- Configure System
- Account For System
- Secure System
- Provide Access

Sample EI Requirements and Attribute Table References



1	Functional Interaction	IPK Value	Functional Role	Req. ID	Requirement Statement	Requirement Status	T1--Managed System Measured Outputs Table	T2	T3	T4--Managed System Controlled Inputs Table	T5	T6--Human Outputs Table	T7--Human System Managers Table	TA--Alarms, Exceptions, and Notifications Table	TB--Regulatory Control Loops Table	TC--Discrete Control (Loops) Table	TD--Interlocks Table	TE--Recipe Capabilities Table	TF--Operational Sequence Table	TG--SOPs Table	TH--Logs and History Table	TI--Calculated Variable Table	TJ--Equipment Module Table	TK	TL--System Response Table	TM--Failure Sequence Table	TN--Reports Table	S1--Sensors Table	S2--Actuators Table
198	Maintain System	301.3 Automated Fault Data Analysis	Maintainer	AUTO 4012	The maintainer shall receive, understand, and act upon the fault data analysis reports listed in the Reports Table as routed to the maintainer and associated with Automated Fault Data Analysis.	Ready For Review																					X		
199	Maintain System	301.3 Automated Fault Data Analysis	Managed System (Level N)	AUTO 4011	The system shall automatically generate the fault data analysis reports listed in the Reports Table as associated with Automated Fault Data Analysis, upon the trigger events and for the report consumers listed there.	Ready For Review																					X		
200	Maintain System	301.3 Automated Fault Data Analysis	Management System (Level N+1)	AUTO 4013	The system shall receive and process the fault data analysis reports listed in the Reports Table as routed to the supervisory management system and associated with Automated Fault Data Analysis.	Ready For Review																					X		
201	Maintain System	301.4 Process Context Automatic Fault Data Logging	Maintainer	AUTO 4084	The maintainer shall receive and understand the historical fault data log views, displays, or reports of the types [Report Type], including process context data, listed in the Reports Table, when indicated in that table as maintainer directed by [Data Consumer], requesting these if so indicated in that table by [Triggering Event].	Ready For Review																					X		
202	Maintain System	301.4 Process Context Automatic Fault Data Logging	Managed System (Level N)	AUTO 4081	The system shall transmit fault data for faults found in the Alarms, Exceptions, and Notifications Table that are listed in the Logged Data Table, for capture by external management system log, including process context data.	Ready For Review								X							X								
203	Maintain System	301.4 Process Context Automatic Fault Data Logging	Management System (Level N)	AUTO 4081.1	The system shall transmit fault data for faults found in the Alarms, Exceptions, and Notifications Table that are listed in the Logged Data Table, including process context data, for capture by external management system log.	Ready For Review								X							X								
204	Maintain System	301.4 Process Context Automatic Fault Data Logging	Management System (Level N+1)	AUTO 4082	The system shall receive and record fault data for faults found in the Alarms, Exceptions, and Notifications Table that are listed in the Logged Data Table from the managed system, along with the [Additional Logged Context Data], for subsequent generation of log	Ready For Review								X							X								
	Maintain System	301.4 Process Context	Management System	AUTO	The system shall produce the historical logged fault data views,	Ready For																							



Pattern

Configuration

Feature

FPK
Attribute
Attribute
Attribute

Feature-Interaction Table

Feature	FPK	Interaction	IPK Rule

Functional Interaction

IPK

Interaction-Role-Requirement Table

Interaction	Role	Requirement	RSPK Rule

Requirement Statement

RSPK
Attribute
Attribute

Functional Role

RPK
Attribute
Attribute

Role-Phys Compon Table

Role	Phys Comp	IPPK Rule

Interaction – Role Table

Interaction	Role	RPK Rule

Design Component

IPPK
Attribute
Attribute

Attribute Coupling

ACPK

Populated by User, from Stakeholder Needs

Populated by Pattern (Auto)

Populated by Pattern (Auto)

Populated by Pattern (Auto)

Populated by Pattern (Auto)

Populated by User or Pattern (Auto)

Configured Feature

FPK
Attribute
Attribute
Attribute

Values

User Visible

Configured Functional Interaction

IPK

Populated by Pattern (Auto)

Populated by Pattern (Auto)

Populated by Pattern (Auto)

PK Value Set by Pattern (Auto)

User Visible

Configured Requirement Statement

RSPK
Attribute
Attribute

Values

Configured Functional Role

RPK
Attribute
Attribute
Attribute
Attribute

Req'd Vals

Capability Vals

PK Value Set by Pattern (Auto)

Configured Design Component

PCPK
Attribute
Attribute

Values

User Visible

Attribute Coupling

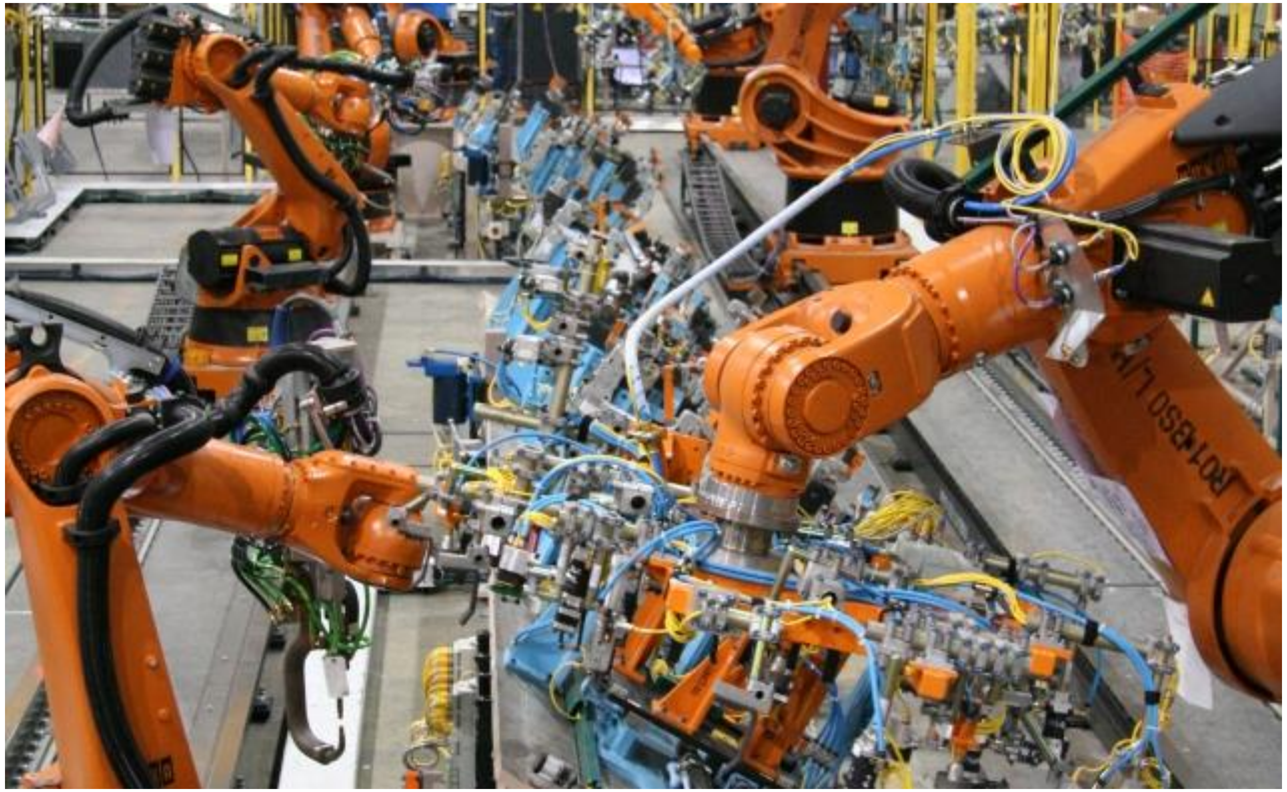
ACPK

User Visible

User Might Typically See Only These

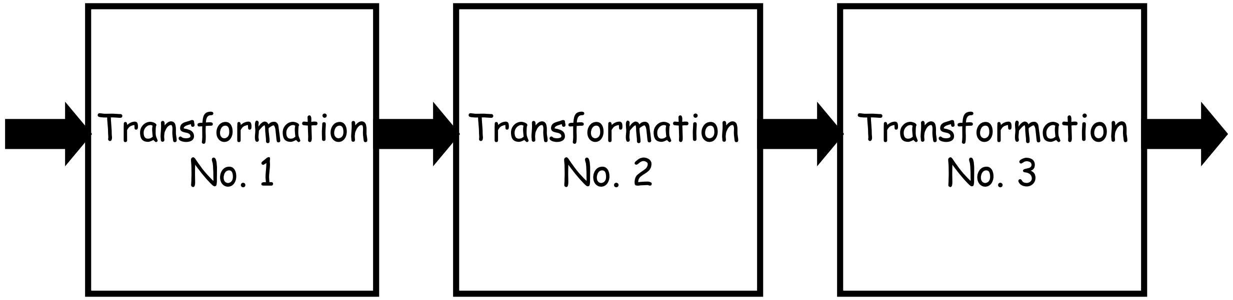
General Manufacturing S*Pattern, with Embedded Intelligence: Smart Manufacturing Pattern for the IoT Age

- For any manufacturing process, and with varied levels of instrumentation and management.



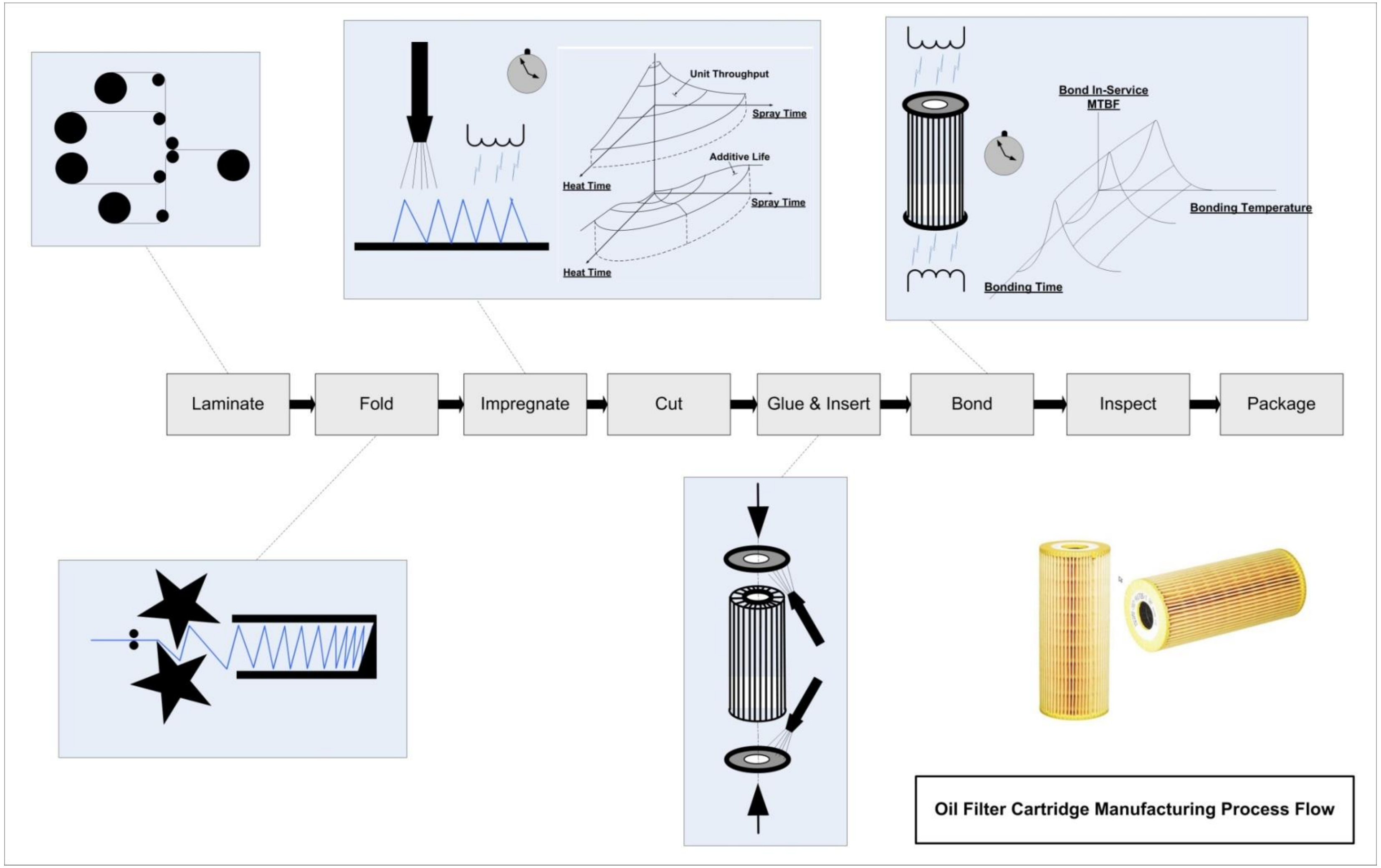
The Process Engineer’s Perspective

- Process Engineers are trained to visualize manufacturing as <u>transformations of material</u> (or of information).
- This is frequently represented graphically using <u>Process Flow Diagrams</u> (PFDs):



- The material flowing <u>out</u> is different than the material flowing <u>in</u>--it is “transformed” chemically, structurally, thermodynamically, as information, visually, etc.

A Simple Example:
Manufacturing Oil Filter Cartridges

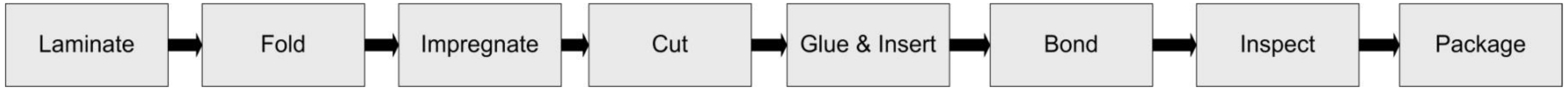


Laminate → Fold → Impregnate → Cut → Glue & Insert → Bond → Inspect → Package

Oil Filter Cartridge Manufacturing Process Flow

Process Engineering vs. Equipment Design

- By omitting equipment-specific design, the PFD perspective has the advantage of emphasizing what is required to be changed (transformed) about the material, without describing how manufacturing equipment, tools, people, or control systems will accomplish those transformations:



- Since it describes the required transformations, it is a form of partial requirements on a manufacturing system.

Process Engineering Challenges

- Process Engineering and Process Flow Diagrams provide powerful tools for conceptualizing manufacturing processes.
- However, the fact they use a perspective or language separate from design of equipment requires that the enterprise bridge a gap when integrating PE into the larger engineering context.
- For example, not all requirements on a manufacturing system are requirements of the process itself—they may even conflict.
- Various enterprises and trade groups have wrestled with the question of integrating the larger engineering process for manufacturing systems . . .

Integration with the larger engineering context: Challenges

1. How can the language and perspective of process engineers be more effectively coupled to those of equipment designers?
2. How do process requirements fit into overall manufacturing system requirements, which have larger scope?
3. What is the relationship of physical equipment design to these requirements?
4. How can process requirements for new or modified products be incorporated early enough in the equipment design cycle?
5. How are manufacturing system requirements that are not transformation of materials related to this?
6. How can we conceive new manufacturing solutions without being mentally trapped in assuming constraints of past designs?
7. How can candidate manufacturing designs, design changes, or design risks be evaluated in light of process engineering needs?
8. How are industry reference models of manufacturing (e.g., ISA, ISPE, etc.) related to these issues?
9. More generally, how can increasingly complex advanced manufacturing systems best be engineered, over their life cycles?

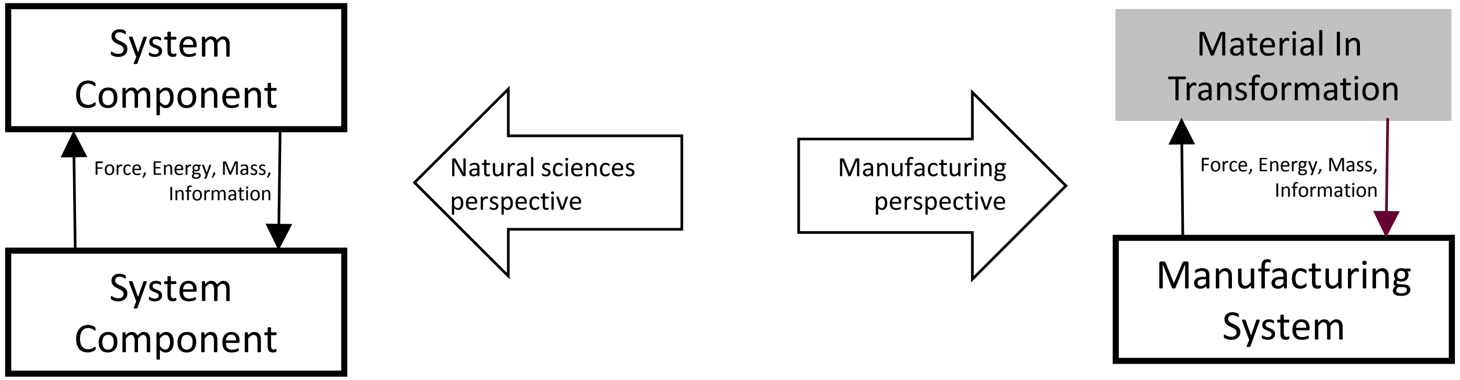
The need for a Science-based Understanding

- Industry trends increasingly emphasize science-based understanding of manufacturing processes:
  - Unit operations: key parametric relationships—materials science, chemistry, physics, etc.
  - First principle and empirical characterizations;
  - Mathematics of production flow;
  - Process capabilities and control laws;
  - Regulatory (e.g., FDA) pressures for a more science-based approach.

- How do we fit science-based understanding into an integrated framework of process and equipment engineering?

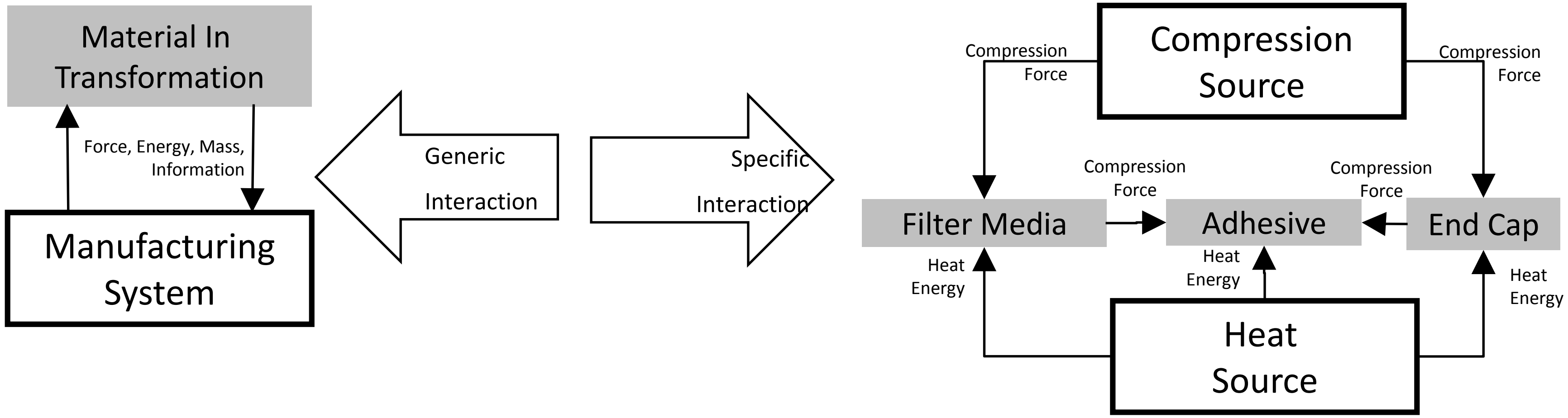
The need for a Science-based Understanding

- *Literally everything we know* from the physical sciences is about the *behavior of interacting system components*—whether in chemical reactions, electromagnetics, acoustics, mechanics, thermodynamics, or other discipline-specific interactions:



- Accordingly, the *interactions* of Materials In Transformation with the Manufacturing System assign "roles" to the *Manufacturing System* and the *Materials*, which are required to be met by what we have learned from sciences and by the results we want.

An example Interaction



Material In Transformation

Force, Energy, Mass, Information

Manufacturing System

Generic Interaction

Specific Interaction

Compression Source

Compression Force

Compression Force

Compression Force

Compression Force

Filter Media

Adhesive

End Cap

Heat Energy

Heat Energy

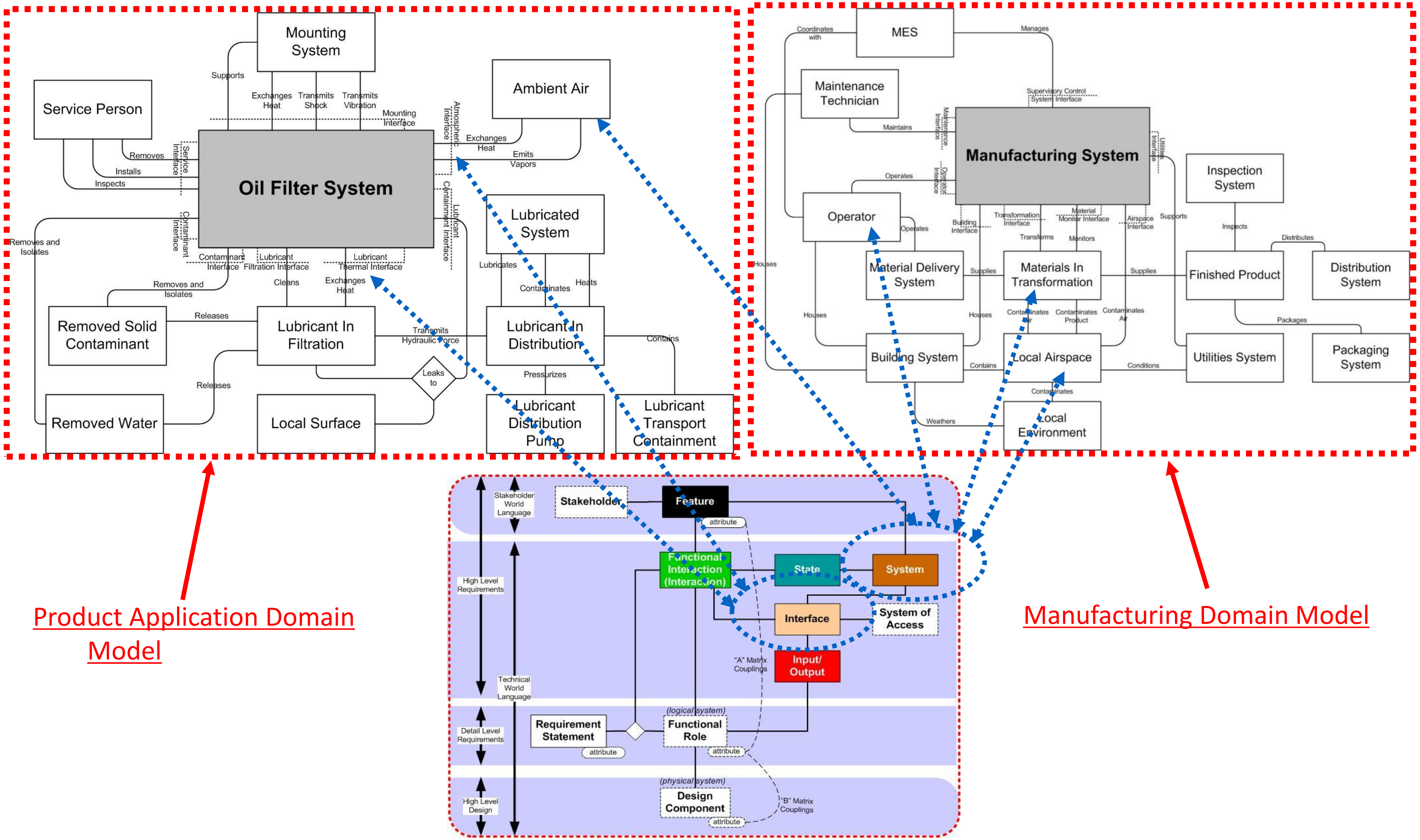
Heat Energy

Heat Source

- Interaction = “Bond Filter Media to End Cap”
- Functional Roles (of materials and equipment):
  - Filter Media
  - End Cap
  - Adhesive
  - Heat Source
  - Compression Source

- Each of these “Roles” includes specific Required Behavior in order to meet expectations for the overall Interaction.
- The Physical Component to which the Role is allocated must meet those requirements—whether Equipment, Materials, or People

Models can describe Manufacturing Systems, as well as Manufactured Products.

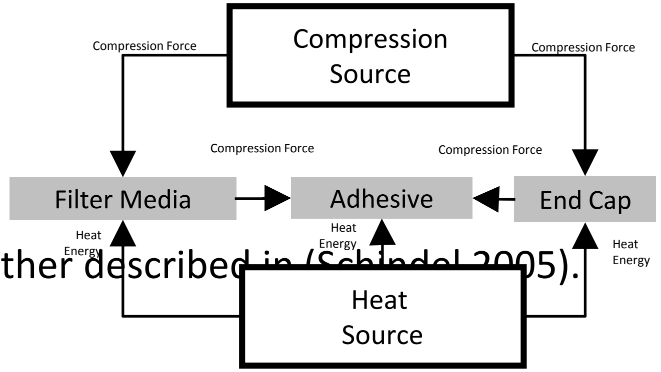


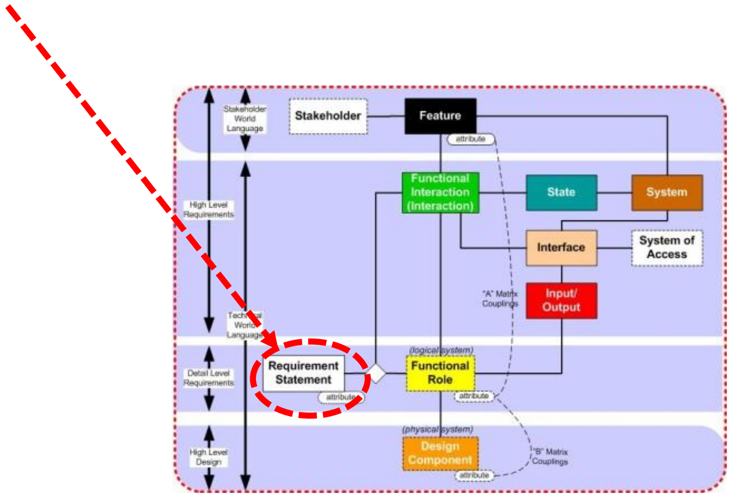
Product Application Domain Model

Manufacturing Domain Model

Modeling transformation behavior

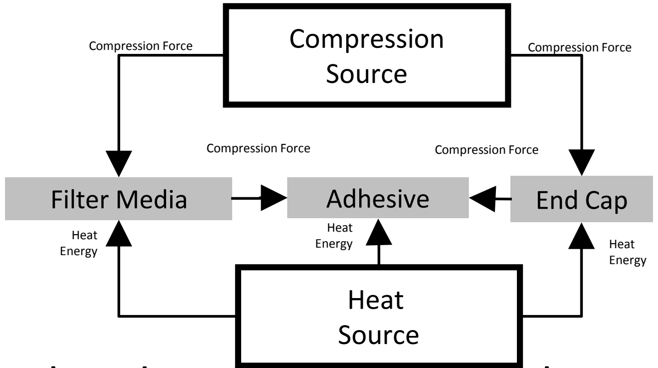
- This Metamodel re-positions prose functional “Requirements Statements”:
  - These textual statements become a formal part of the model.
  - All functional requirements are modeled as external interaction behaviors.
  - They become input-output relationships describing external system “black box” behavior during Interactions with external actors—a “prose transfer function”:
    - *“The Manufacturing System shall deliver to the Materials In Process a Compression Force of [Min Bond Force] for a period of [Min Bond Time]”.*
    - *“The Manufacturing System shall deliver to the Materials in Process Heat Energy sufficient to maintain a bond temperature of [Min Bond Temperature] for a period of [Min Bond Time].”*
  - Further described in (Schindel 2005).





It works for the Materials in Process, as well as the Manufacturing System

- In the same way, in the same model we can describe the required behavior of the Materials in Process:
    - *“The Adhesive, Filter Media, and End Cap shall bond upon input of a Compression Force of [Min Bond Force] for a period of [Min Bond Time], accompanied by input of Heat Energy sufficient to maintain a bond temperature of [Min Bond Temperature] for a period of [Min Bond Time].”*
    - *“The Oil Filter shall operate in service at Lubricant Pressure of [Max Lubricant Pressure] with bond or other structural failure rates less than [Max Structural Failure Rate] over an in-service life of [Min Service Life].”*



Compression Source

Compression Force

Compression Force

Compression Force

Compression Force

Filter Media

Adhesive

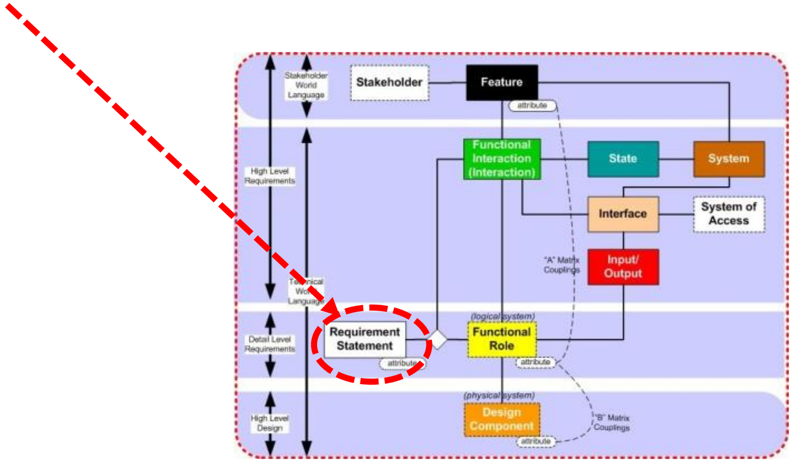
End Cap

Heat Energy

Heat Energy

Heat Energy

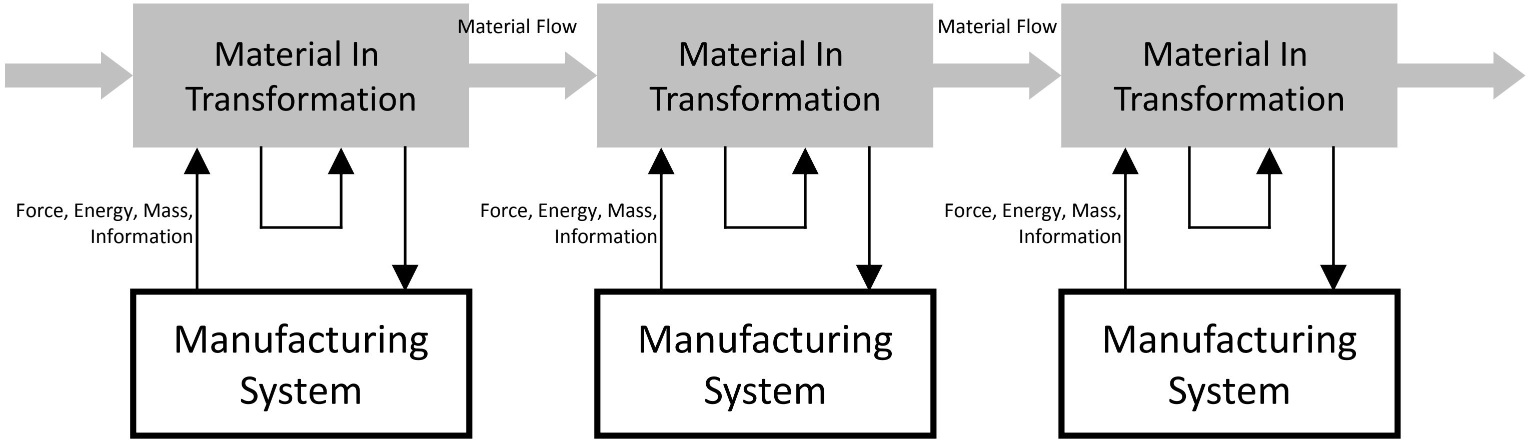
Heat Source



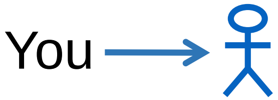
- Further described in (Schindel 2005).

Applying the concepts to manufacturing processes

- For some process engineering specialists, material scientists, or other disciplines, an understanding of the behavior of the material during transformations is essential:
  - bending, forming, structural deformations, cutting, milling, extruding, compression
  - chemical, biochemical, electrochemical reactions, distillation, fermentation, etc.
  - heating, cooling, bonding, welding, fastening, mixing, blending
  - other transformations
- These specialists think about the "Material In Transformation":
  - how the material behaves during each of a series of sequential unit operation transformations;
  - During each transformation, the Material will exchange energy, force, mass, or information with the Manufacturing System, as well as with itself--

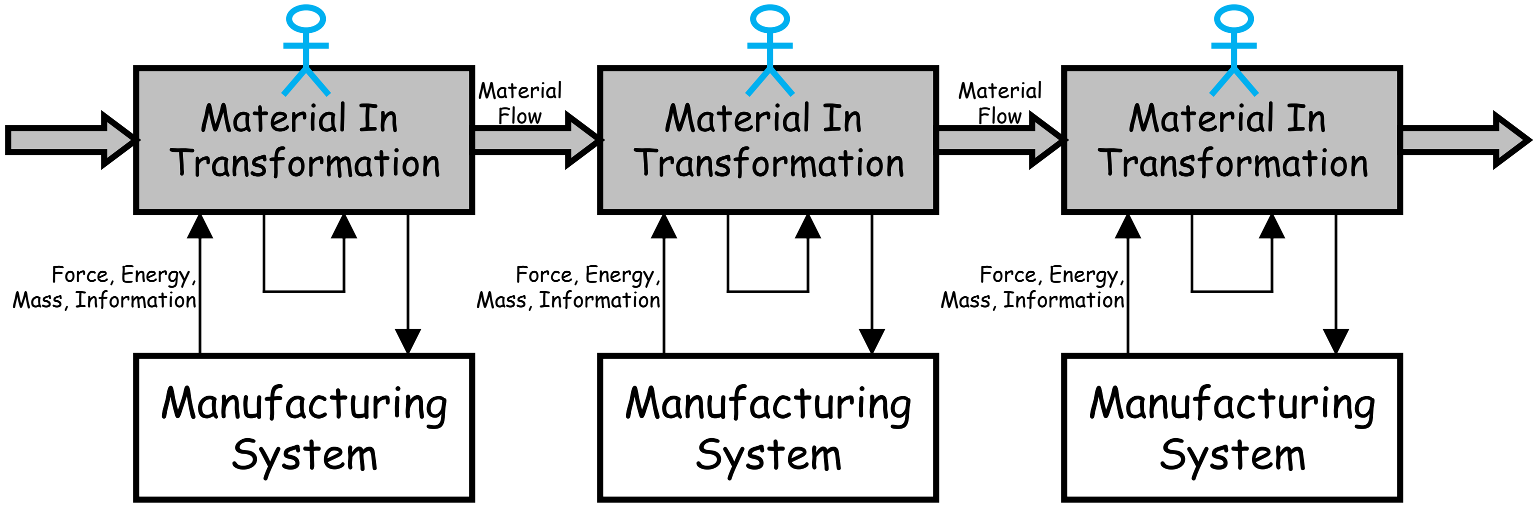


Process: What the Material “Sees”



You

- Imagine that you could “ride through the process with the material”.
- Imagine that you could “see what the material sees” (forces, temperatures, etc.).
- This is the “process view” of the process engineer, materials scientist, chemist, metallurgist, or other process-related specialist:



Material In Transformation

Material Flow

Material In Transformation

Material Flow

Material In Transformation

Force, Energy, Mass, Information

Manufacturing System

Force, Energy, Mass, Information

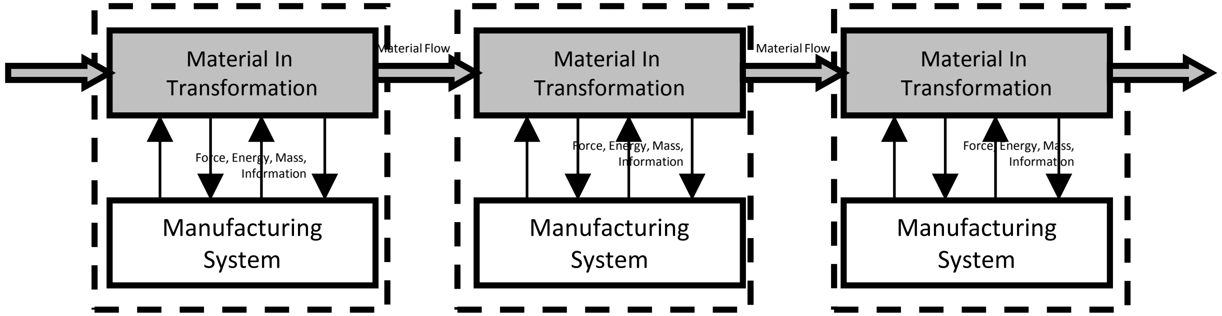
Manufacturing System

Force, Energy, Mass, Information

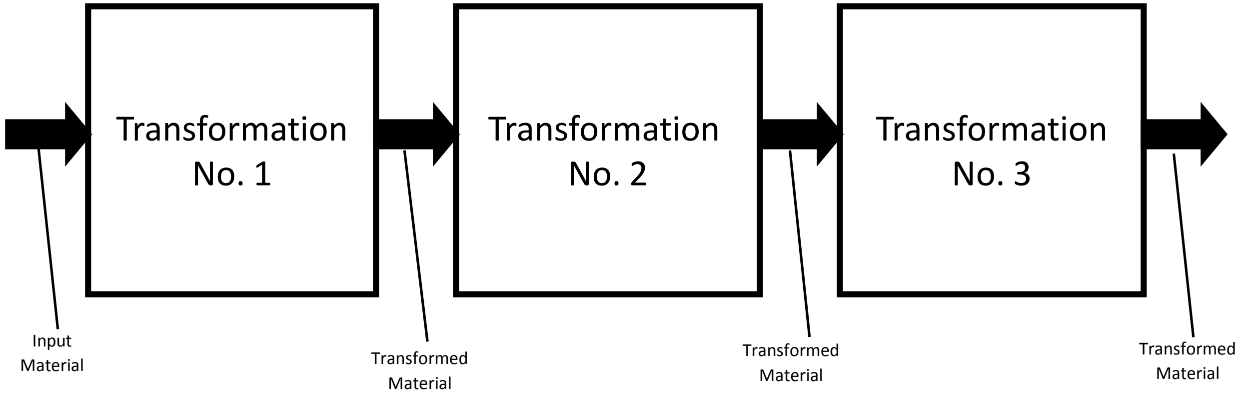
Manufacturing System

Less detailed PFD views

- Others people's jobs don't need that much detail, so they think of the transformations as "black boxes"; so that . . . .

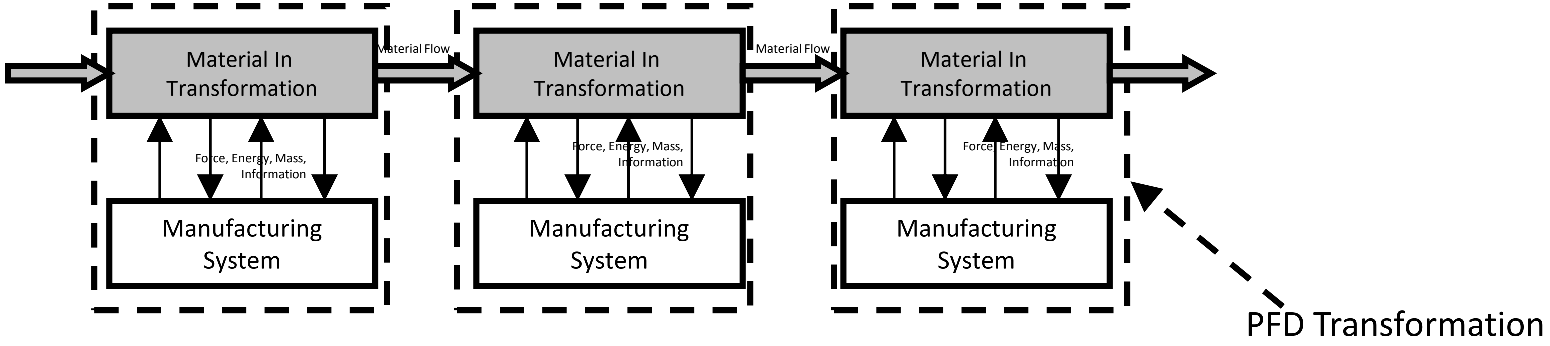


becomes a Process Flow Diagram (PFD):



Material In Transformation can be modeled as “logically outside” the equipment’s transformation role

- Difference between these two representations:
  - the Material In Transformation is “logically outside” the Manufacturing System, but . . .
  - that Material In Transformation is “logically inside” the PFD Transformations:



- After all, the Material In Transformation is not a part of the BOM of the Manufacturing System!
- The advantage of this approach is that it allows us to use the MBSE technique that *all the functional requirements on the manufacturing system are found at the points of input-output boundary crossings of that system*

“Registered Process” As Requirements

- Many manufacturing “processes” have a kind of managed existence separate from their specific implementation with equipment:
  - When a PFD describes a process before there is equipment design;
  - When a “registered process” has been approved by a regulator, and a factory is constructed to implement that specific process;
  - When a low-volume process has come out of a laboratory to a pilot production line, but not yet been scaled up to production volume.

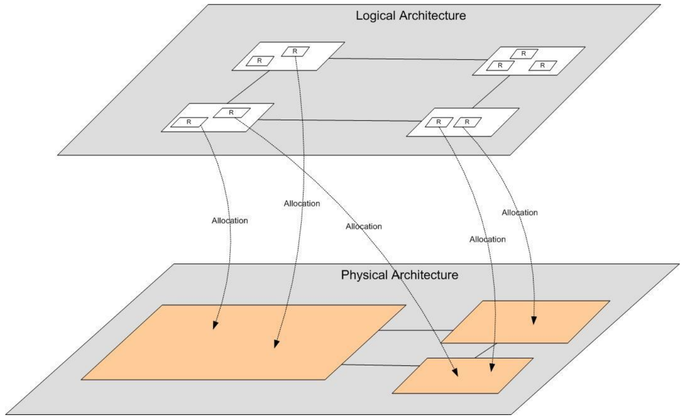
- This reflects the idea that the requirements of a manufacturing system are something more than producing the end outputs from the initial inputs—it is also expected to embody a specific targeted manufacturing process.

- This is why we model the “Materials In Process” as an external actor interacting with the equipment.

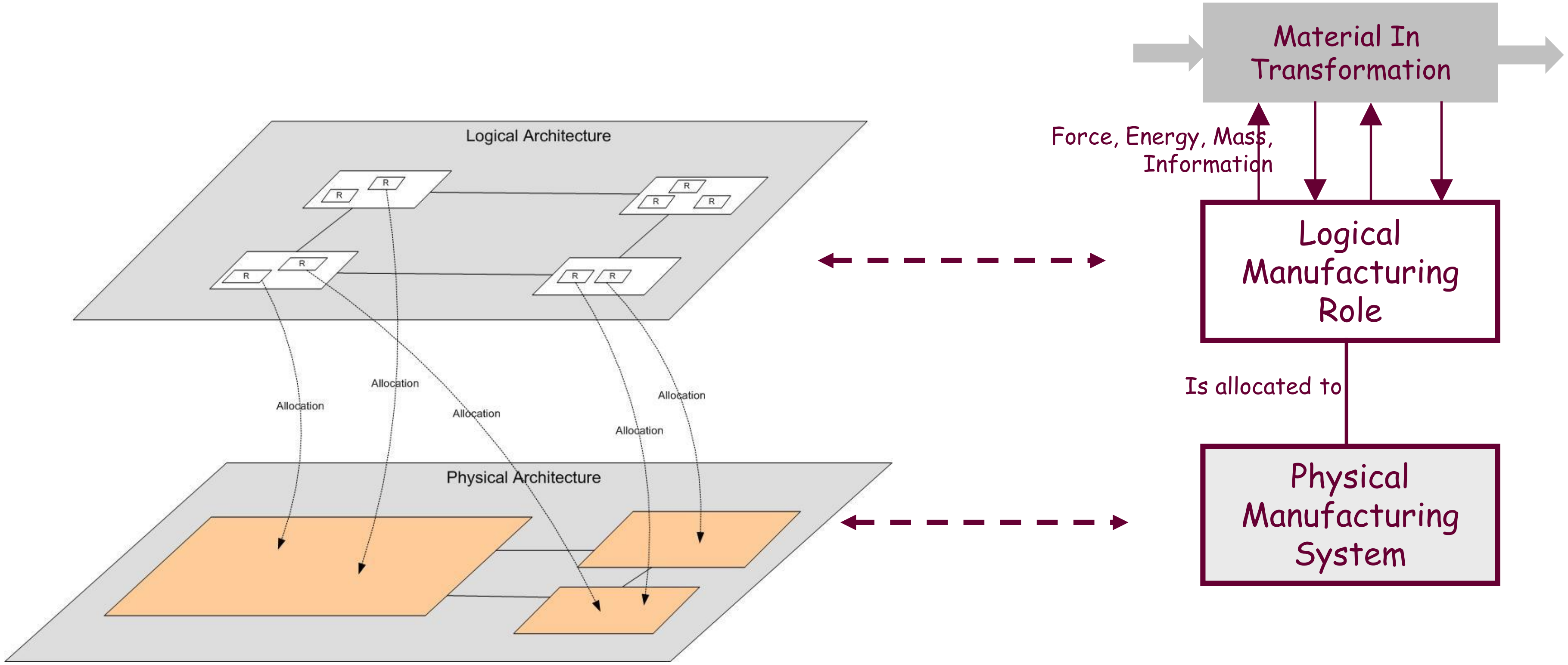
Logical Systems vs. Physical Systems

- MBSE expresses what the Manufacturing System contributes to the process, using Logical Systems:
  - Logical systems are defined by their required externally visible behavior, as seen by the other interacting actors, without regard to the physical design used to accomplish that behavior.

- Logical System Roles:
  - represent transformation or other behavior of the manufacturing system, without regard to its design.
  - Certain Logical Manufacturing Roles must produce (or consume) certain forces, energy, or information, exchanged with the Material In Transformation.
- Physical Manufacturing Systems:
  - Are defined by their physical identity, not their behavior.
  - Logical behaviors are then allocated to physical equipment.
- Logical Roles are allocated to Physical Systems



Logical Systems vs. Physical Systems



Material In Transformation

Force, Energy, Mass, Information

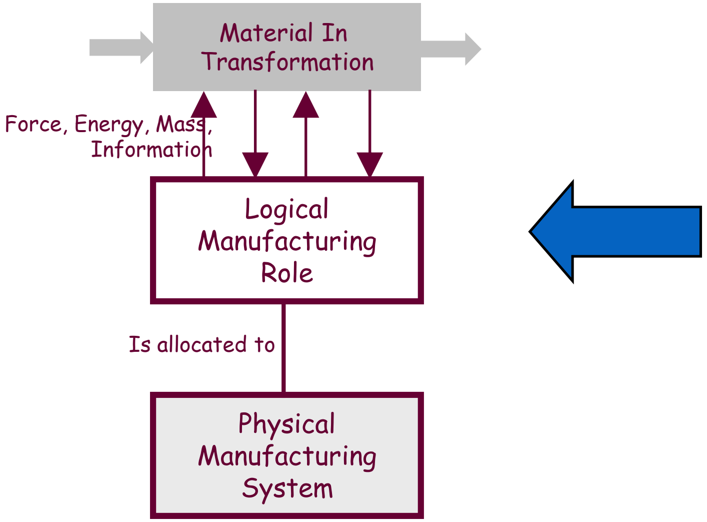
Logical Manufacturing Role

Is allocated to

Physical Manufacturing System

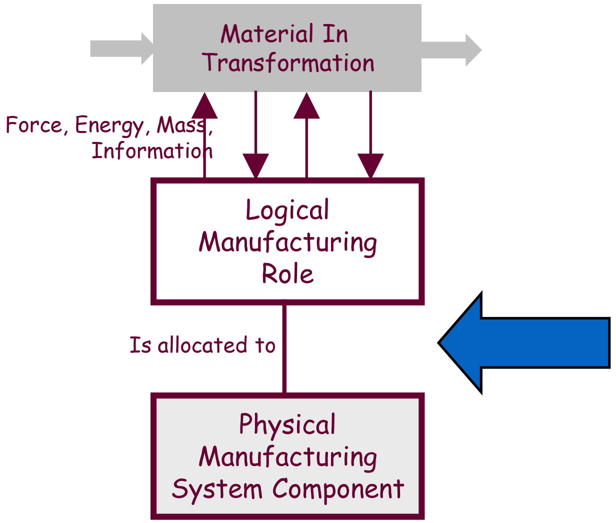
Manufacturing system requirements

- The input-output relationships (relationships between input-output Forces, Energies, Masses, Information that are exchanged with the Material In Transformation) of the Logical Manufacturing Roles turn out to express the requirements allocated to the Manufacturing System to accomplish the transformation:



Manufacturing equipment design

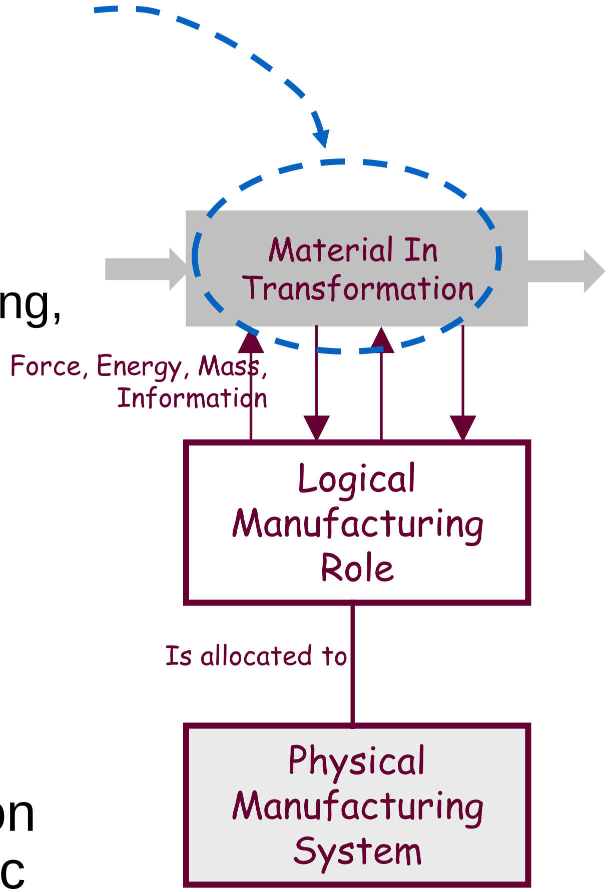
- The allocation of logical manufacturing roles to physical equipment components describes the high level design of the manufacturing system:



- ➢ This begins the embedding of process requirements into an integrated framework of system requirements.

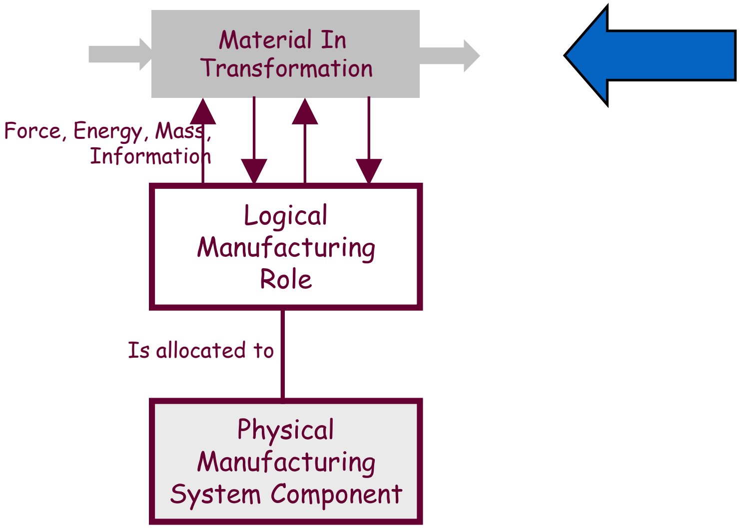
Materials roles

- For materials scientists, chemists, metallurgists, and other specialists in materials . . .
- These specialists seek out materials that have properties desirable for transformations:
  - bending, forming, structural deformations, cutting, milling, extruding, compression
  - chemical, biochemical, electrochemical reactions, distillation, fermentation, etc.
  - heating, cooling
  - bonding, welding, fastening
  - mixing, blending
  - other transformations
- The logical transformation model facilitates description of those properties, somewhat independent of specific materials:
  - Encourages understanding of materials requirements and opens thinking to new materials solutions.

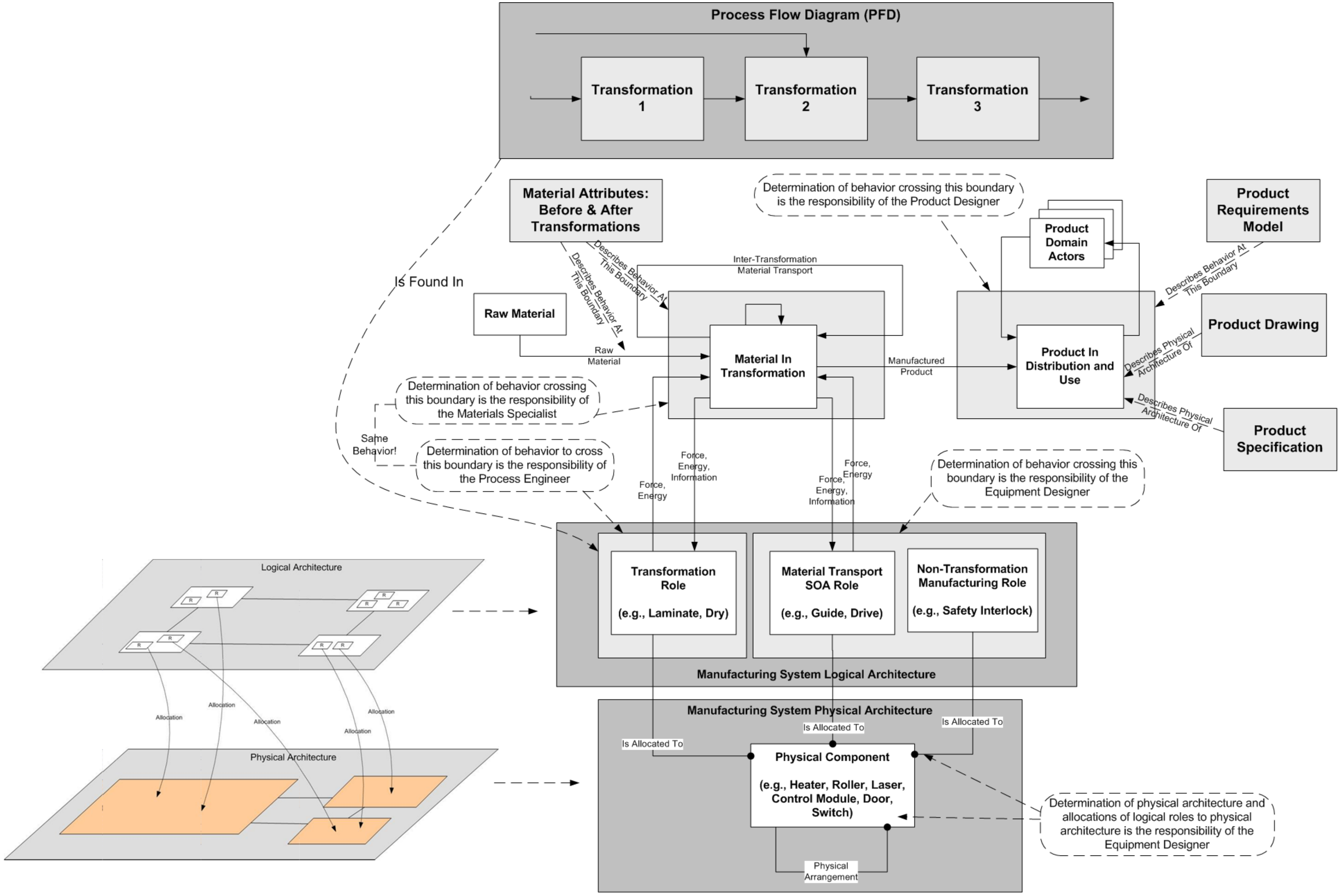


Materials roles

- Just like the equipment, logical roles are allocated to the Materials In Transformation, which they must satisfy in order for the transformation (or transport) to succeed:



- This means that we can create an integrated model that couples the roles of interest to the process engineer and equipment design with those of interest to the materials specialist . . . .



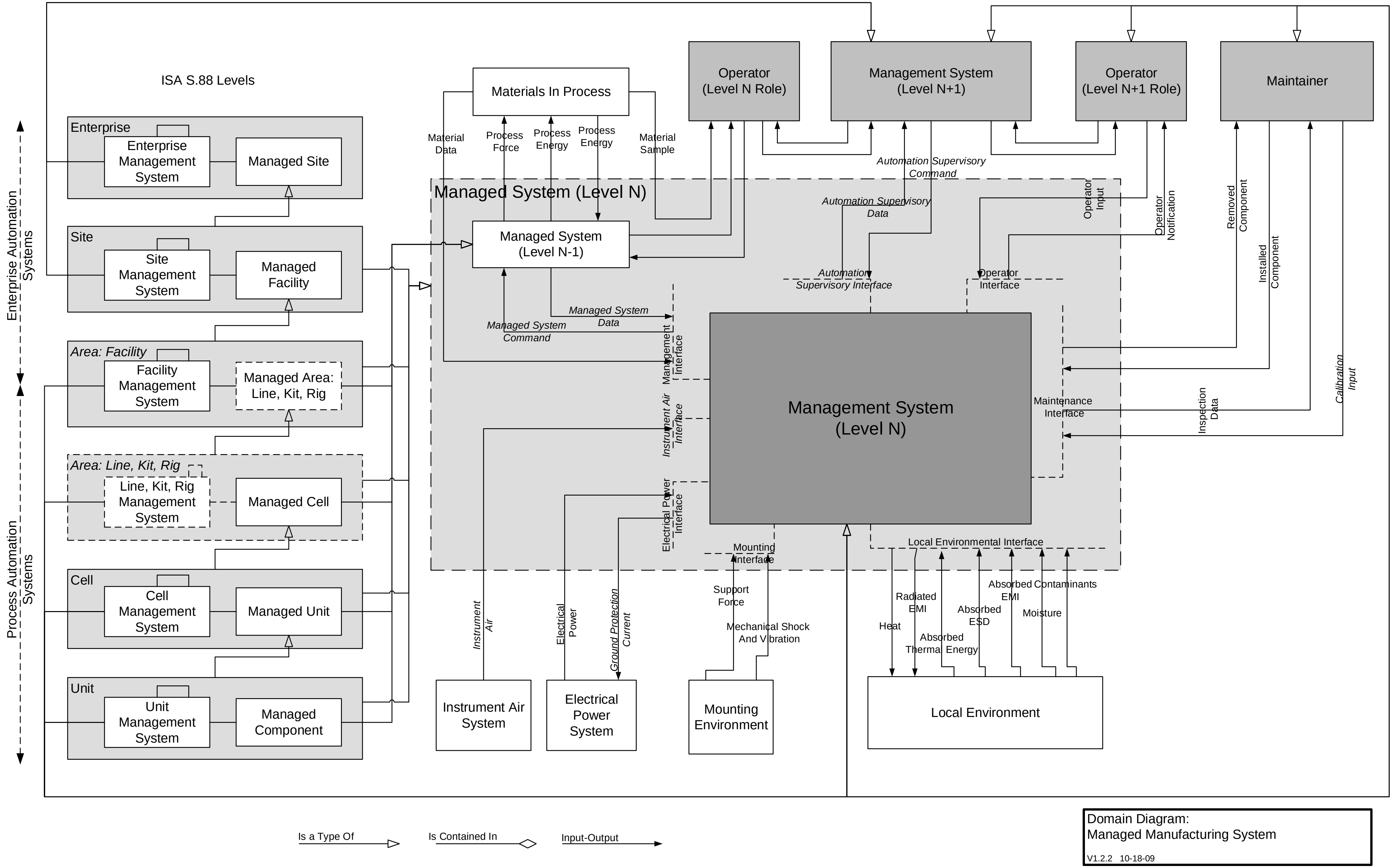
Logical and Physical Architecture, Cross-Domain Development & Engineering Roles

Sample Pattern Extracts

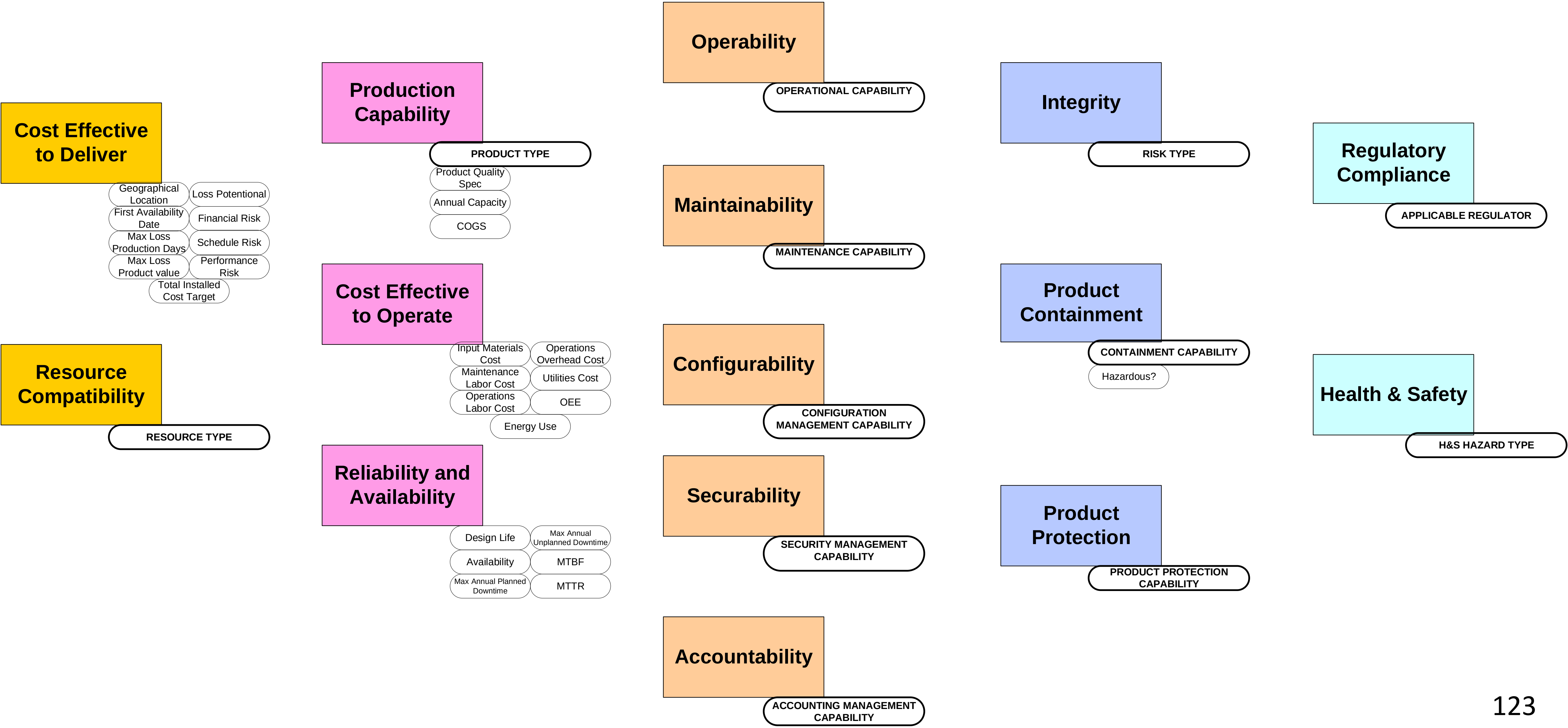
From Smart Manufacturing Pattern:

- Manufacturing Domain Model and Hierarchy
- Manufacturing Feature Model—Generic Level
- Sample Manufacturing Interaction Models
- Sample Manufacturing Systems of Access Models

Manufacturing Domain Model and Hierarchy



Manufacturing Feature Model—Generic Level



Cost Effective to Deliver

- Geographical Location
- Loss Potentional
- First Availability Date
- Financial Risk
- Max Loss Production Days
- Schedule Risk
- Max Loss Product value
- Performance Risk
- Total Installed Cost Target

Resource Compatibility

RESOURCE TYPE

Production Capability

PRODUCT TYPE

- Product Quality Spec
- Annual Capacity
- COGS

Cost Effective to Operate

- Input Materials Cost
- Operations Overhead Cost
- Maintenance Labor Cost
- Utilities Cost
- Operations Labor Cost
- OEE
- Energy Use

Reliability and Availability

- Design Life
- Max Annual Unplanned Downtime
- Availability
- MTBF
- Max Annual Planned Downtime
- MTTR

Operability

OPERATIONAL CAPABILITY

Maintainability

MAINTENANCE CAPABILITY

Configurability

CONFIGURATION MANAGEMENT CAPABILITY

Securability

SECURITY MANAGEMENT CAPABILITY

Accountability

ACCOUNTING MANAGEMENT CAPABILITY

Integrity

RISK TYPE

Product Containment

CONTAINMENT CAPABILITY

- Hazardous?

Product Protection

PRODUCT PROTECTION CAPABILITY

Regulatory Compliance

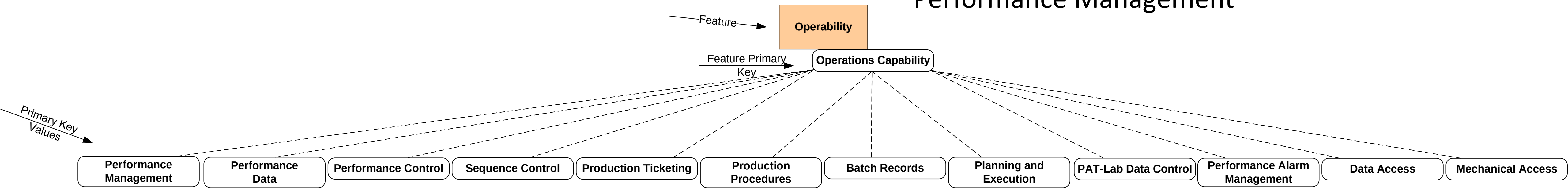
APPLICABLE REGULATOR

Health & Safety

H&S HAZARD TYPE

Manufacturing Feature Specialization by Feature Primary Keys

Operability, AKA
Performance Management



Operability

Operations Capability

Performance Management

Performance Data

Performance Control
- -502.3: Automatic Performance Feedback Control
- -502.4: Semi Automatic Performance Feedback Control
- -502.5: Manual Performance Control
- -502.6: No Performance Control

Sequence Control
- -503.1: Automatic Sequence Control-Batch Context
- -503.2: Automatic Sequence Control-Basic
- -503.3: Semi-Automatic Sequence Control-Batch Context
- -503.4: Semi-Automatic Sequence Control-Basic
- -503.5: Manual Sequence Control

Production Ticketing
- -504.1: Integrated Electronic Production Ticket
- -504.2: Electronic Production Ticket
- -504.3: Paper Production Ticket

Production Procedures
- -505.1: Electronic Work Instructions
- -505.2: Integrated Procedure Access
- -505.3: Electronic Procedures
- -505.4: Paper Procedures

Batch Records
- -506.1: Electronic Batch Record
- -506.2: Electronic Batch Reports
- -506.3: Paper Batch Record

Planning and Execution
- -508.1: Basic Manufacturing Execution Management
- -508.2: Integrated Manufacturing Execution
- -508.3: Paper Based Production Planning and Scheduling
- -508.4: Production Planning and Scheduling Management Integration

PAT-Lab Data Control
- -509.1: PAT Based Feedback Control
- -509.2: PAT Measurement
- -509.3: Automatic Material Sampling
- -509.4: Manual Material Sampling
- -510.1: Integrated LIMS Interface for Feedback Control
- -510.2: Lab Data Manual Entry for Feedback Control
- -510.3: No Lab Data Entry

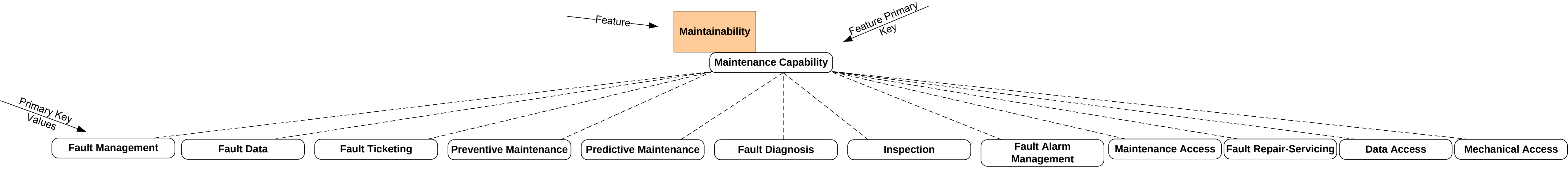
Performance Alarm Management

Data Access
- -HMI
- -Network
- -Sensors
- -Actuators
- -External Systems
- -Instrumentation

Mechanical Access
- -Basic Tools
- -Special Tools
- -Access Space
- -Access Ladders

Manufacturing Feature Specialization by Feature Primary Keys

Maintainability, AKA
Fault Management



Feature

Maintainability

Feature Primary Key

Maintenance Capability

Primary Key Values

Fault Management

-301.1: Maintenance Supervisory Management Integration

-301.3: Automated Fault Data Analysis

-302.4: Automated Fault History Analysis

Fault Data

-301.4: Process Context Automatic Fault Data Logging

-301.5: Automatic Fault Data Logging

-301.6: Process Context Automatic Fault Detection and Display

-301.7: Automatic Fault Detection and Display

-301.8: Manual Fault Data Logging

-301.9: Manual Fault Detection

Fault Ticketing

-302.1: Automated Fault Ticketing

-302.2: External Fault Ticketing

-302.3: Manual Fault Ticketing

Preventive Maintenance

-303.1: Automated PM Routine Ticketing

-303.2: External PM Routine Ticketing

-303.3: Manual Preventive Maintenance Scheduling

Predictive Maintenance

-304.1: Predictive Maintenance Ticketing

-304.2: Predictive Fault Capability

-304.3: Built-In Self Test

-303.4: External Predictive Maintenance Capability

-303.5: No Predictive Maintenance Capability

Fault Diagnosis

-305.2: Automatic Fault Diagnosis

-305.4: Manual Fault Diagnosis

Inspection

-306.1: Manual Inspection and Routine Servicing

-306.3: Maintenance HMI

Fault Alarm Management

-307.2: Automated Alarm Management

-307.3: Alarm Classification

-307.4: No Alarm Management

Maintenance Access

-305.3: Manual Fault Correction or Repair

Fault Repair-Servicing

Data Access

-HMI

-Network

-Sensors

-Actuators

-External Systems

-Instrumentation

Mechanical Access

-Basic Tools

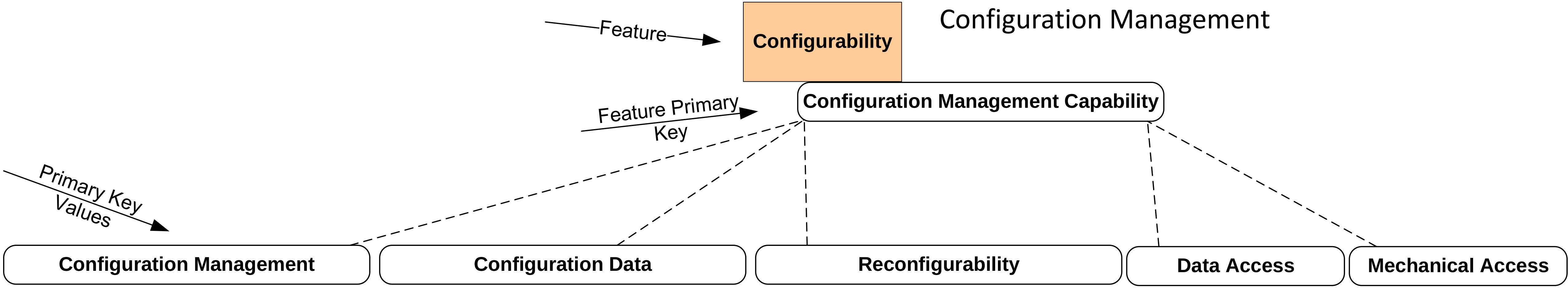
-Special Tools

-Access Space

-Access Ladders

Manufacturing Feature Specialization by Feature Primary Keys

Configurability, AKA
Configuration Management



Configurability

Configuration Management Capability

Configuration Management

- **-201.1: Configuration Supervisory Management Integration**

Configuration Data

- **-202.1: Automatic Configuration Data Logging**
- **-202.2: Process Context Automatic Configuration Data Logging**
- **-202.3: Manual Configuration Data Logging**
- **-203.1: Automatic Configuration Data Measurement and Display**
- **-203.2: Process Context Automatic Configuration Data Measurement and Display**
- **-203.3: Manual Configuration Data Measurement**

Reconfigurability

- **-204.1: Automatic Reconfigurability**
- **-204.2: Semi-Automatic Reconfigurability**
- **-204.3: Manual Reconfigurability**

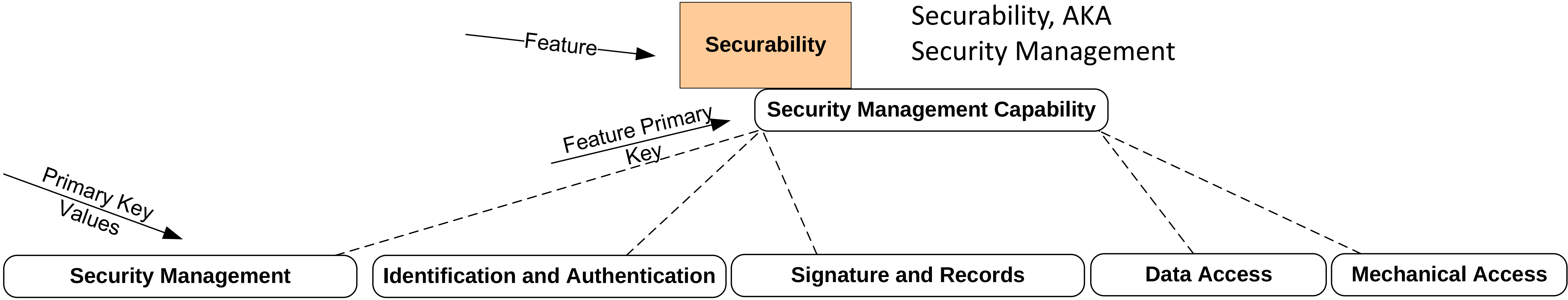
Data Access

- **-HMI**
- **-Network**
- **-Sensors**
- **-Actuators**
- **-External Systems**
- **-Instrumentation**

Mechanical Access

- **-Basic Tools**
- **-Special Tools**
- **-Access Space**
- **-Access Ladders**

Manufacturing Feature Specialization by Feature Primary Keys



Feature

Securability

Securability, AKA
Security Management

Feature Primary Key

Security Management Capability

Primary Key Values

Security Management

Identification and Authentication

Signature and Records

Data Access

Mechanical Access

-401.1: Security Supervisory Management Integration

-401.2: Automated Security History Analysis

-401.3: Internal Security Logging

-403.1: Automatic Operational Privileges Authorization

-403.2: Manual Operational Privileges Authorization

-402.1: Biometric Based Identification and Authentication

-402.2: Automatic Identification and Authentication

-402.3: Manual Security Identification and Authentication

-404.1: Electronic Signature Capability

-404.2: Electronic Record Capability

-404.3: Hybrid Electronic Records Capability

-404.4: Paper Records and Signatures

-HMI

-Network

-Sensors

-Actuators

-External Systems

-Instrumentation

-Basic Tools

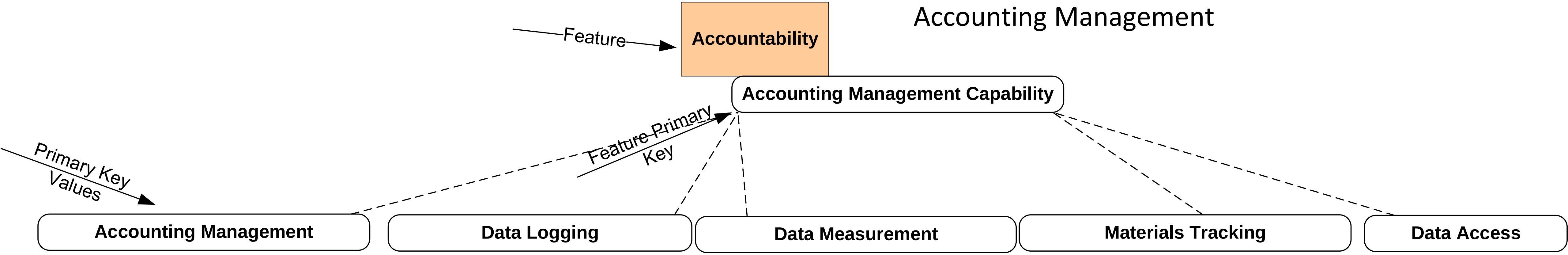
-Special Tools

-Access Space

-Access Ladders

Manufacturing Feature Specialization by Feature Primary Keys

Accountability, AKA
Accounting Management



-101.1: Accounting Supervisory Management Integration

-101.2: Automated Accounting Analysis

-102.1: Process Context Automatic Utilization Data Logging

-102.2: Automatic Utilization Data Logging

-102.5: Manual Utilization Data Logging

-102.3: Process Context Automatic Utilization Data Measurement and Display

-102.4: Automatic Utilization Data Measurement and Display

-102.6: Manual Utilization Data Measurement

-103.1: Automatic Materials Utilization Tracking Capability

-103.2: Manual Materials Utilization Tracking Capability

-HMI

-Network

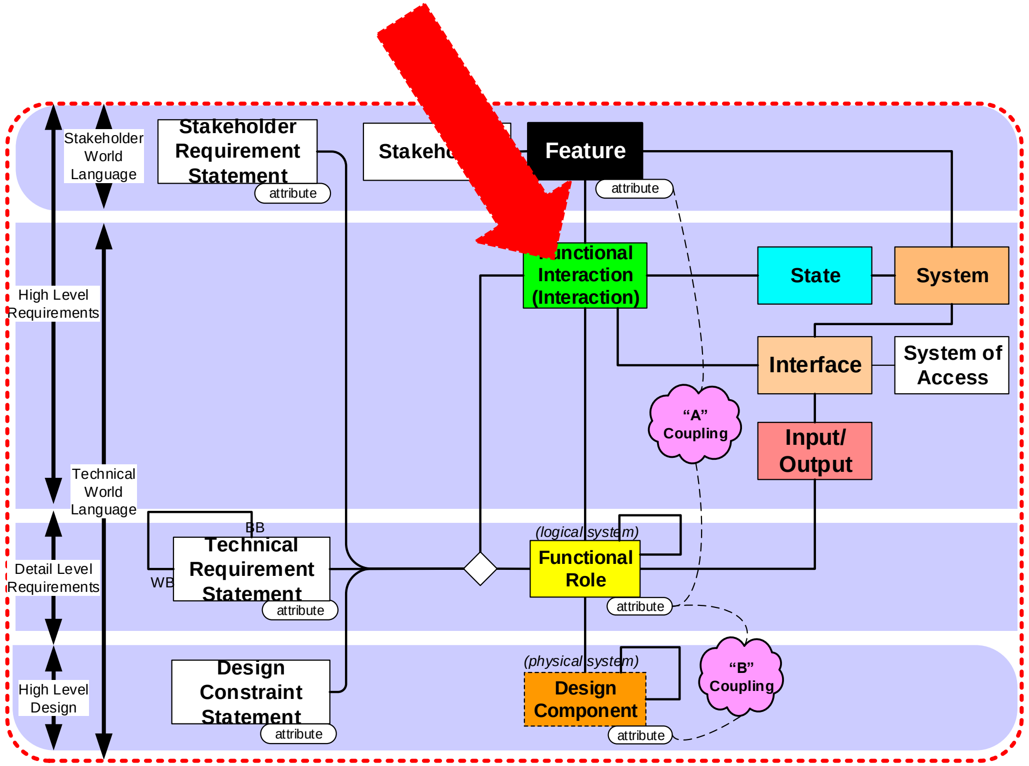
-Sensors

-Actuators

-External Systems

-Instrumentation

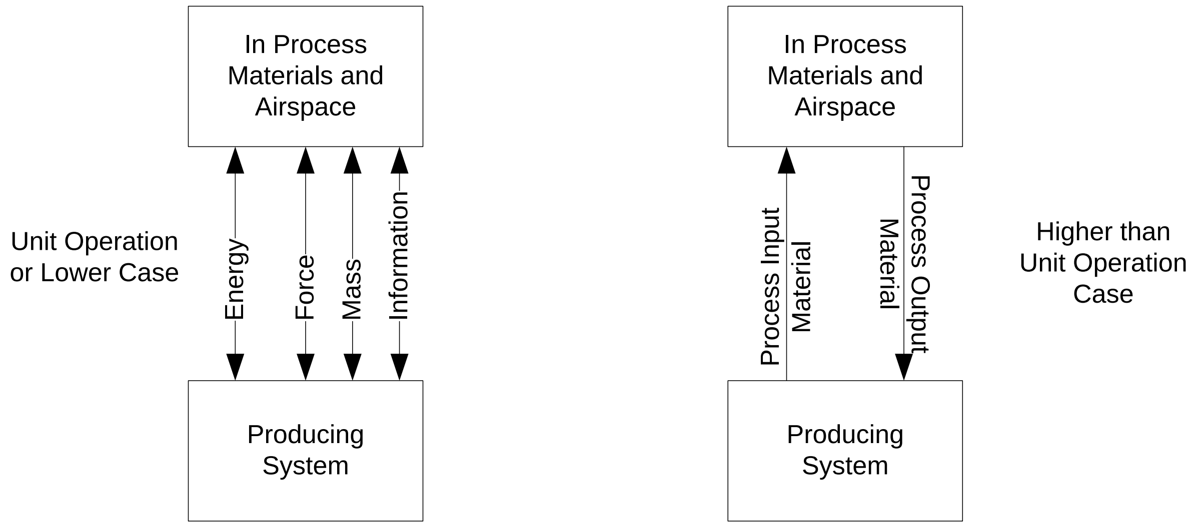
Manufacturing Interactions: Generic



- Operate System
- Maintain System
- Configure System
- Account For System
- Secure System
- Provide Access
- Transform Material
- Transport Material
- Deliver System
- Consume Utility
- Protect

Interaction: Transform Material

Definition:	The interaction between process equipment and materials in process in which the materials' structural, chemical, or other physical aspects are altered.
Model Information:	Only Unit Operation (or lower) level cases model material transformation forces, transformation energy, and transformation mass flows that occur during the transformation process, as seen by the material in process. Higher level cases model only the pre and post interaction materials. The attributes of the process and materials are modeled according to this same division.
Other related interactions:	Receiving and providing raw, in-process, or finished materials are part of the Transport Material interaction, not this interaction. The scope of this interaction does not include the management of transformation processes by human or automated means—for those aspects, refer to Operate System.



Unit Operation or Lower Case

In Process Materials and Airspace

Energy

Force

Mass

Information

Producing System

In Process Materials and Airspace

Process Input Material

Process Output Material

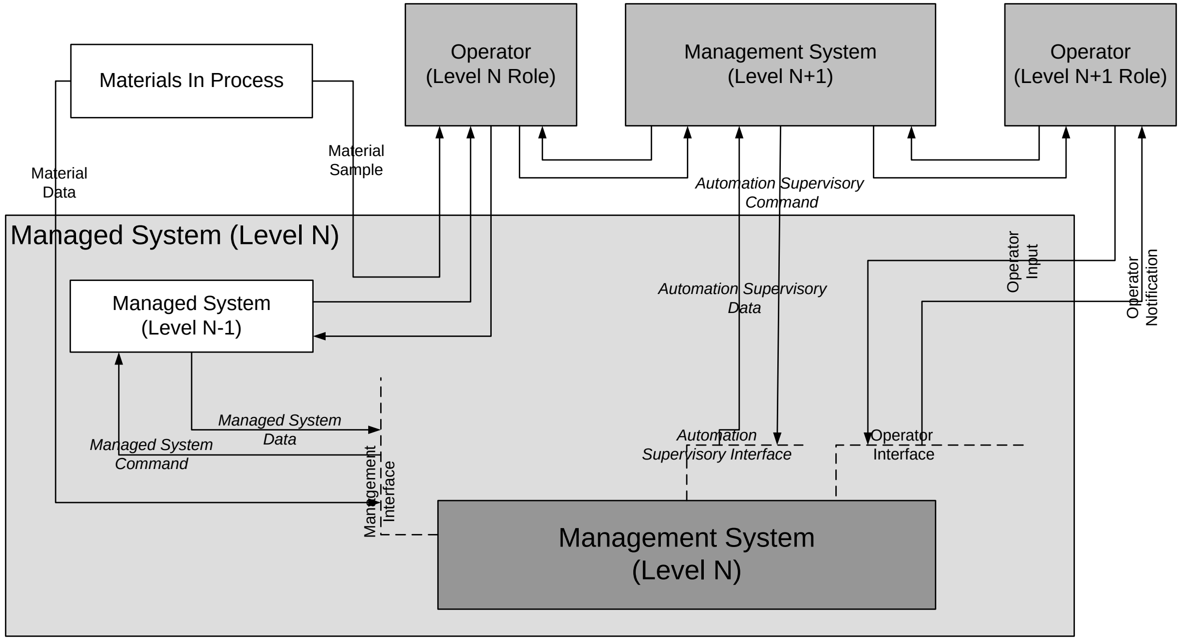
Producing System

Higher than Unit Operation Case

Interaction: Operate System

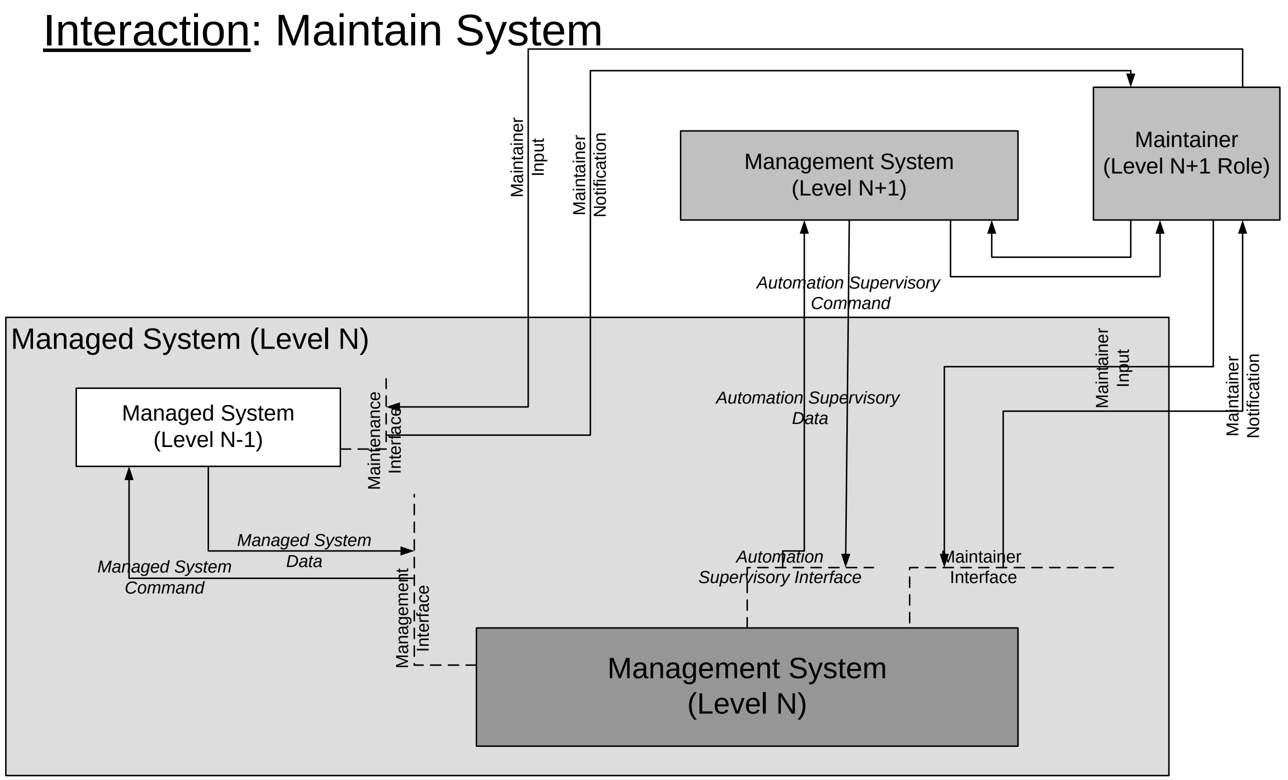
Definition:	The interaction of a managed system with a higher level management system and/or operators and managers acting in higher level management roles, through which the performance of the managed system in its basic mission is managed. The scope of this interaction does not include the actual production transformations of the managed system, but is focused on the management of their performance. It does not include management of faults, configuration, security, or accounting aspects.
Other Related Interactions:	Transform Material; Maintain System; Configure System, Secure System, Account for System.
Primary Key Values:	

<u>Interaction</u>: Operate System



Interaction: Maintain System

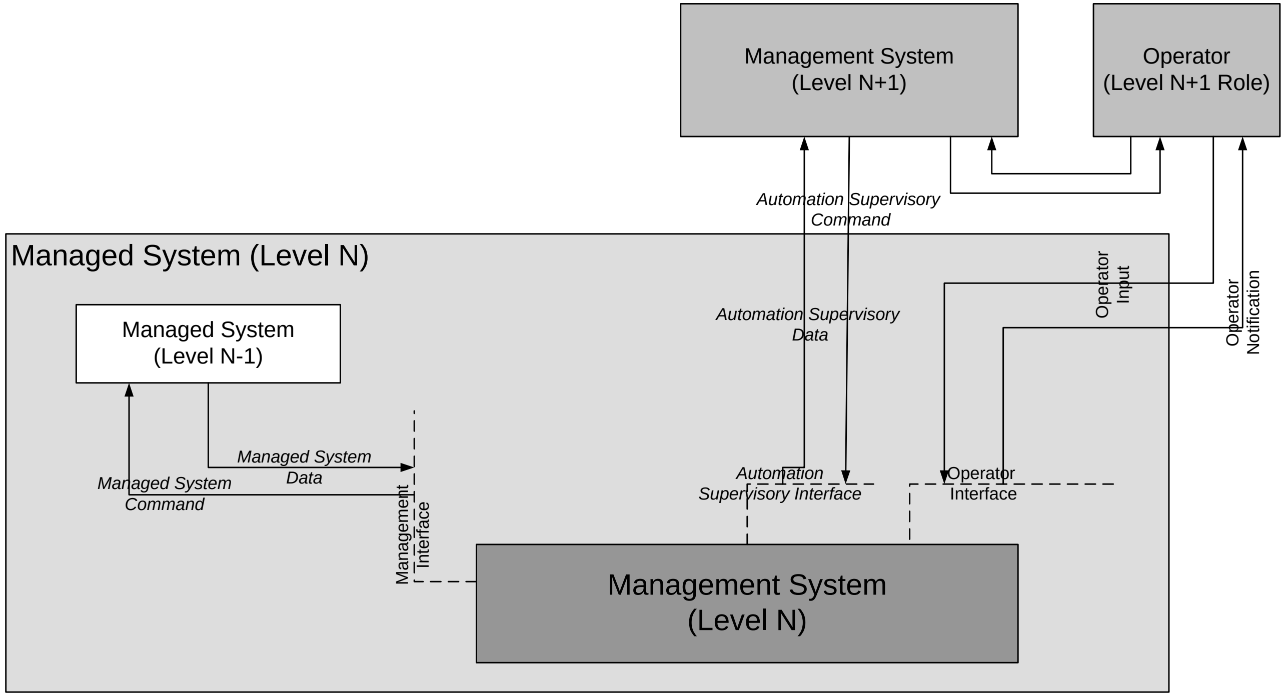
Definition:	The interaction of maintenance occupants and higher level management systems with a managed system, for purposes of maintaining that system in a qualified or appropriate state for its intended purpose. This includes all forms of maintenance -- the prevention of faults (preventive maintenance), as well the detection, diagnosis, recovery, and repair of faults (corrective maintenance).



Interaction: Configure System

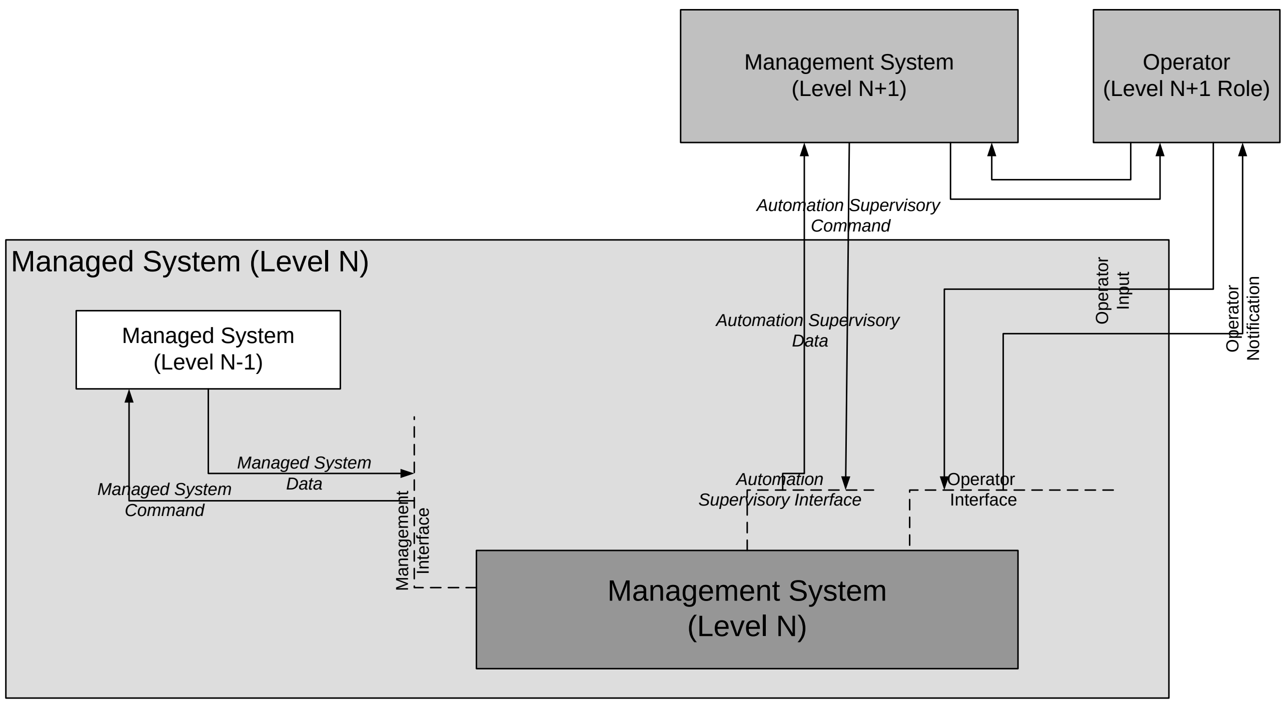
Definition:	The interaction of a managed system with a higher level management system and/or operator acting in a higher level management role, through which the configuration of the managed system is managed.

Interaction: Configure System



Interaction: Secure System

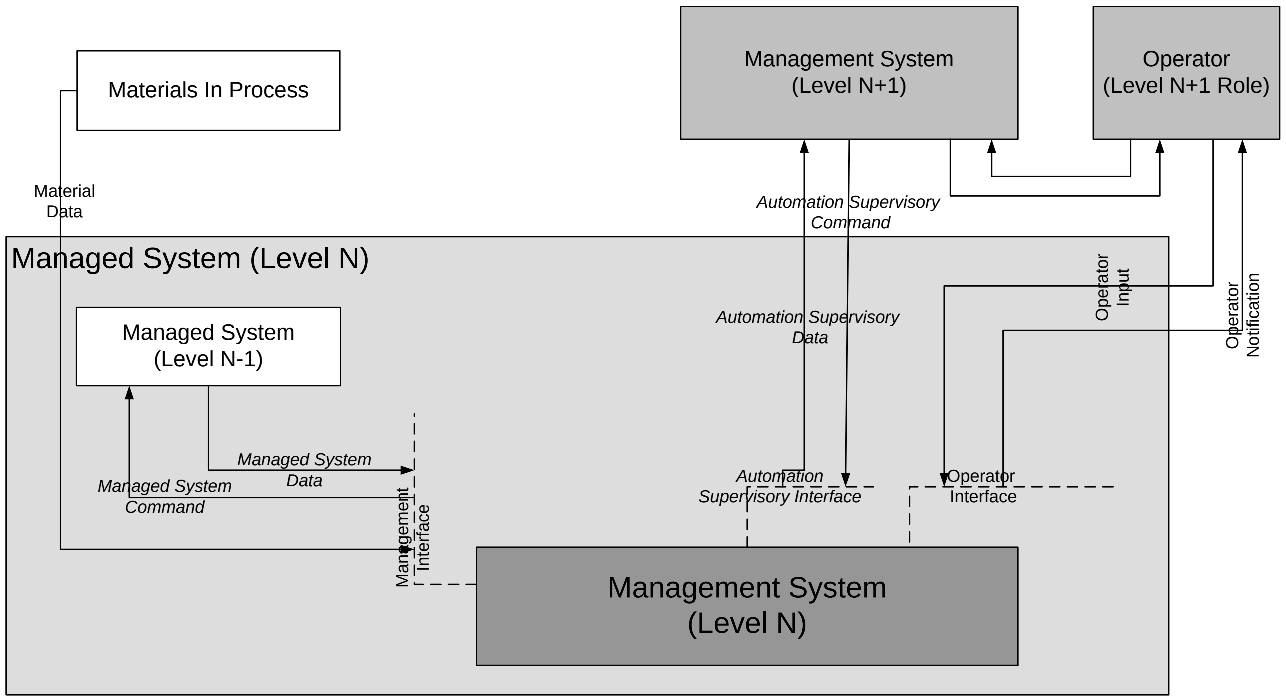
Definition:	The interaction of a managed system with a higher level management system and/or operators acting in a higher level management role, through which the security of the managed system assets and capabilities is managed.


Interaction: Secure System

Interaction: Account for System

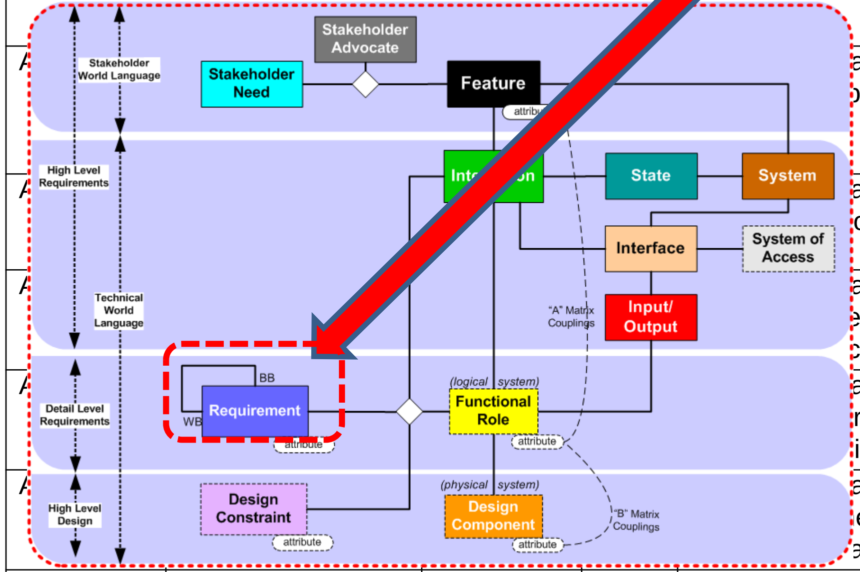
Definition:	The interaction of a managed system with a higher level management system and/or operator acting in a higher level management role, through which the utilization of the resources or capabilities of the managed system is accounted for.

<u>Interaction</u>: Account for System



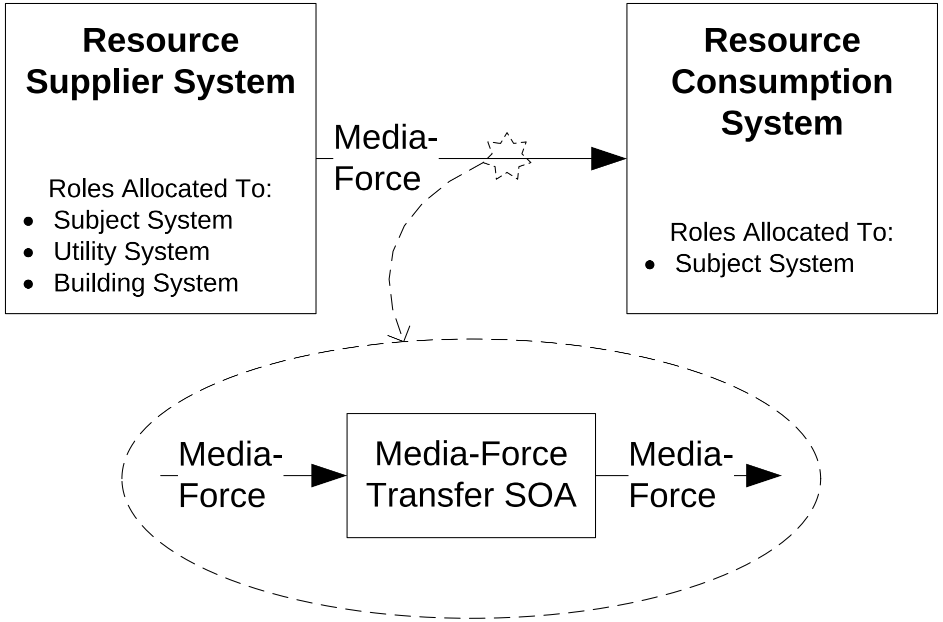
Account for System: Requirements

Interaction	Interaction Primary Key	Role	Req ID	Requirement
Account for System	101.2 Automated Accounting Analysis	Managed System (Level N)	AUTO 6001	The system shall produce the system accounting analysis outputs, views, displays, or reports as listed in the Reports Table.
Account for System	102.1 Process Context Automatic Utilization Data Logging	Managed System (Level N)	AUTO 6011	The system shall transmit tem utilization data, as shown in the Logged Data Table, for capture by external managemer ystem log, including process context data.
Account for System	102.2 Automatic Utilization Data Logging	Managed System (Level N)	AUTO 6021	The system sh ansmit system utilization data, as shown in the Logged Data Table, for capture by external agement system log.
Account for System	102.3 Process Context Automatic	Managed System	AUTO 6031	The sy n shall measure and display system utilization data as listed in the Managed System Mea ed Outputs Table, including process context data and including a status of data indicator.
A				all measure and display system utilization data as listed in the Managed System puts Table, including a status of data indicator.
A				all display or report system utilization data as shown in the Logged Data Table, for or logging of such data.
A				all all the operator to manually measure the system utilization data listed in the em Measured Outputs Table, for those listed for the Manual Utilization Data capability.
A				all display, indicate, or report the materials utilization data listed in the Managed red Outputs Table, for those listed for the Automatic Materials Utilization Tracking including a status of data indicator.
A				all depend upon external (Operator) capture and tracking of materials utilization e Managed System Measured Outputs Table, for those listed for the Manual ation Tracking capability, and including a status of data indicator.
Account for System	Accounting Management Regulations	Managed System (Level N)	GS_AM_AR_1	The system shall provide accounting management capabilities such that it complies with the regulations required by the regulators listed in the Applicable Regulators Table.



Interaction: Consume Utility

Definition:	The interaction whereby utilities are transferred between systems.
Model Information:	Instances of this interaction may involve production input and outputs, raw materials, utility media supplies and returns, exhaust, energy, mounting/support forces, vibrations, etc. A subject system may be a source (supplier) of one instance of media or force transfer and a sink (destination) to another. Media or force transfer interactions imply a hidden system of access (SOA) role that may be detailed in selected specialized patterns.



Resource Supplier System

Roles Allocated To:
- Subject System
- Utility System
- Building System

Media-Force

Resource Consumption System

Roles Allocated To:
- Subject System

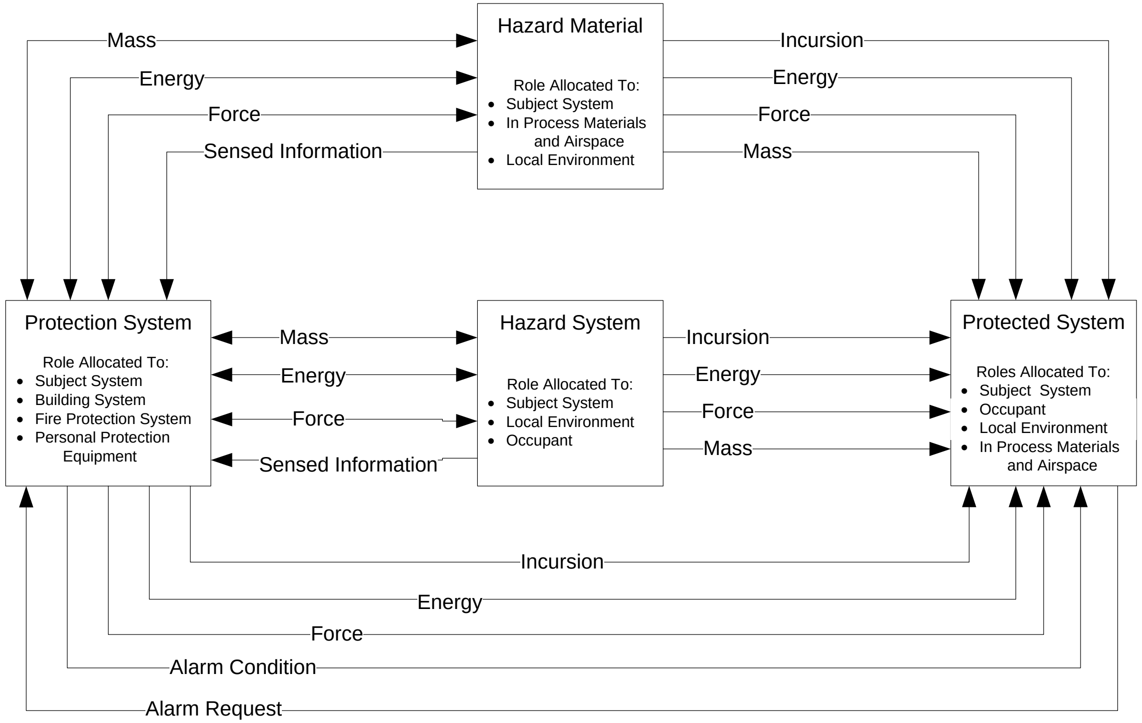
Media-Force

Media-Force Transfer SOA

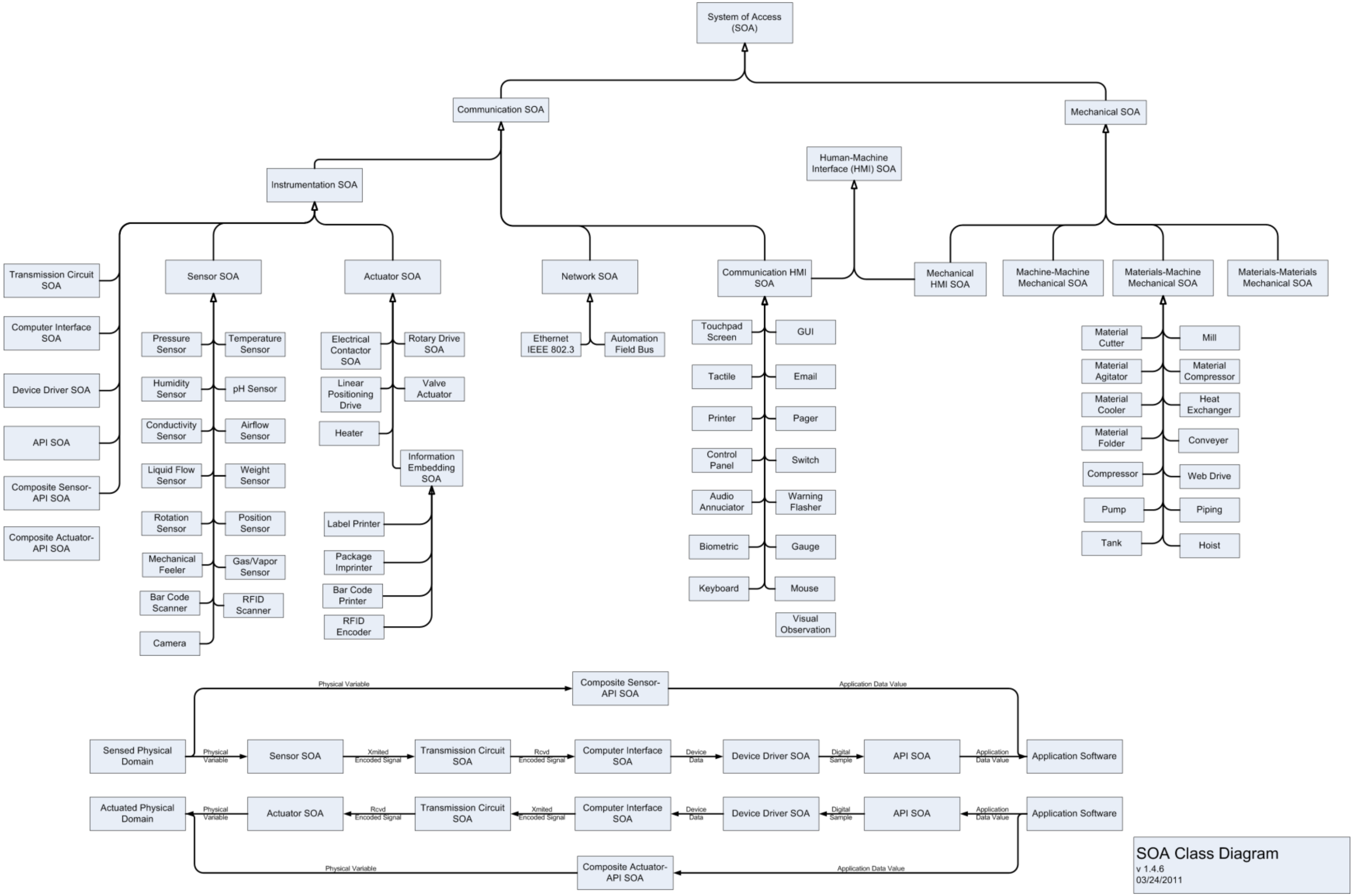
Media-Force

Interaction: Protect

Definition:	The interaction of a subject system with external actors (other systems, people, product and material, and the system's environment) such that the subject system itself, the external systems, people, product and material, and the subject system's environment are protected from hazards originating in each other. This includes maintaining structural integrity, along with distribution of and protection from static and dynamic forces.
Model Information:	A given instance of this interaction may have any of its four common roles allocated to either the Subject System or any of the External Actors interacting with the Subject System.



Example Systems of Access (SOA) Families in Manufacturing Systems Domain



- System of Access (SOA)
  - Communication SOA
    - Instrumentation SOA
      - Transmission Circuit SOA
      - Computer Interface SOA
      - Device Driver SOA
      - API SOA
      - Composite Sensor-API SOA
      - Composite Actuator-API SOA
      - Sensor SOA
        - Pressure Sensor
        - Temperature Sensor
        - Humidity Sensor
        - pH Sensor
        - Conductivity Sensor
        - Airflow Sensor
        - Liquid Flow Sensor
        - Weight Sensor
        - Rotation Sensor
        - Position Sensor
        - Mechanical Feeler
        - Gas/Vapor Sensor
        - Bar Code Scanner
        - RFID Scanner
        - Camera
      - Actuator SOA
        - Electrical Contactor SOA
        - Rotary Drive SOA
        - Linear Positioning Drive
        - Valve Actuator
        - Heater
        - Information Embedding SOA
          - Label Printer
          - Package Imprinter
          - Bar Code Printer
          - RFID Encoder
    - Network SOA
      - Ethernet IEEE 802.3
      - Automation Field Bus
    - Communication HMI SOA
      - Touchpad Screen
      - GUI
      - Tactile
      - Email
      - Printer
      - Pager
      - Control Panel
      - Switch
      - Audio Annuciator
      - Warning Flasher
      - Biometric
      - Gauge
      - Keyboard
      - Mouse
      - Visual Observation
  - Human-Machine Interface (HMI) SOA
    - Communication HMI SOA
    - Mechanical HMI SOA
  - Mechanical SOA
    - Mechanical HMI SOA
    - Machine-Machine Mechanical SOA
    - Materials-Machine Mechanical SOA
      - Material Cutter
      - Mill
      - Material Agitator
      - Material Compressor
      - Material Cooler
      - Heat Exchanger
      - Material Folder
      - Conveyer
      - Compressor
      - Web Drive
      - Pump
      - Piping
      - Tank
      - Hoist
    - Materials-Materials Mechanical SOA

Sensed Physical Domain → Physical Variable → Sensor SOA → Xmited Encoded Signal → Transmission Circuit SOA → Rcvd Encoded Signal → Computer Interface SOA → Device Data → Device Driver SOA → Digital Sample → API SOA → Application Data Value → Application Software

Sensed Physical Domain → Physical Variable → Composite Sensor-API SOA → Application Data Value → Application Software

Actuated Physical Domain ← Physical Variable ← Actuator SOA ← Rcvd Encoded Signal ← Transmission Circuit SOA ← Xmited Encoded Signal ← Computer Interface SOA ← Device Data ← Device Driver SOA ← Digital Sample ← API SOA ← Application Data Value ← Application Software

Actuated Physical Domain ← Physical Variable ← Composite Actuator-API SOA ← Application Data Value ← Application Software

SOA Class Diagram
v 1.4.6
03/24/2011

V4I Model Repository Reference S*Pattern

- Intended primarily as a reference framework (requirements, design, otherwise) for describing this large space, and offerings (third party or otherwise) within it.
- Because of its wide breadth:
  - It expected that most practical cases will be federated sets of COTS and other information systems, not any single system—at least, not for configurations including a large number of the Features listed by the reference pattern.
  - This S*Pattern is currently focused on the (configurable) Stakeholder Features, pending further discussion.
- One or more specific configurations of this framework are expected to be illustrated by real systems during the Launch Projects—whether made mostly or only partly of existing COTS, enterprise, of institutional systems and platforms, or additional components.
- A key value of this framework is as an open reference for others, encouraging a large community—not a single proprietary implementation.

Features of Model Repository

Persistent Model Repository

Repository features providing persistent (memory) services for virtual models of systems

Model Credibility Support

Repository features supporting credibility of shared models

Compatibility

Repository features supporting the compatibility of virtual models across representations, media, and life cycle tooling

Community of Interest and Teaming Support

Repository features supporting collaboration and community use of models

Fit to User and Use

Repository features associated with fitness of the Repository to intended use and users

Model Application Transaction Support

Repository features supporting repository transactions specific to targeted applications of the repository

Model-Based Pattern Support

Repository features supporting reusable configurable model-based patterns

Model Life Cycle Management

Repository features supporting management of the life cycle of models.

Repository System Sustainability

Repository features sustaining its sustainability

Configurable Repository Deployment

Repository features supporting varied deployment options

Repository Release Roadmap

Repository features release plan

Notes:

- This pattern is a specialization of the S*Repository Pattern.
- A specific repository configuration may have a populated subset of the features of this pattern framework.
- This is a Feature pattern describing the trade space for such repositories, but the appearance of a Feature in the above model is no guarantee that it can be supported in an implemented system, unless it appears in the configured Features for that system.

V4I Model Repository Feature Model: Summary Feature Groups

Systematica™

Do more with less

Version: 1.2.1

Date: 30 Oct 2017

Drawn By: ICTT System Sciences

Features of Model Repository

Persistent Model Repository

Repository Service
- Persistent Repository Service
  - SERVICE INSTANCE
  - Persistence
  - Capacity
  - Availability
- Repository Organization
  - ORGANIZATION CAPABILITY
- Model Portfolio Management
  - PORTFOLIO CAPABILITY
- Computational Model – System Model Integration

Model-Based Representations
- Conceptual Model Representation
  - Conceptual Model Representation Type
  - Conceptual Model Interoperability
- Executable Model Representation
  - Executable Model Representation Type
  - Executable Model Interoperability
- Physics Based Model Support
- Data Driven Model Support
- Model Representation Linearization

Non-Model Representations
- Document
  - DOCUMENT TYPE
- Database
  - Database Type

Model Scope and Content
- Model Scope and Content Support
  - CONTENT AREA
    - *Fitness & Value*
    - *External Behavior*
    - *Explanatory Decomposition*
    - *Failure Modes & Effects*
    - *Data-Driven Predictor*
    - *Parametric Couplings, Fitness*
    - *Parametric Couplings, Decomposition*
    - *Parametric Couplings, Characterization*
    - *Physical Architecture*
- Multi-Level System Model Support
- Component Model Support
- Model Dataset Support

Model Credibility Support
- Model Verification Support
- Model Validation Support
- Model UQ Support
- Model VVUQ Pattern Support
- Relying Stakeholder
  - STAKEHOLDER
- Regulatory Entity
  - REGULATOR

Compatibility

Model Semantic Compatibility
- Metadata Integration Capability
- Adaptability to Model Semantics
  - SEMANTICS TYPE
- Schema and Ontology Mapping

- Technical Compatibility Standards Compliance
  - STANDARD
- External References Access

Info Systems Compatibility
- Modeling Tools Compatibility
- Engineering Tools Compatibility
- Simulation Tools Compatibility
- PLM Systems Compatibility
- Learning Tools Compatibility
- Collaboration Tools Compatibility
- HPC Infrastructure Access Facilitation
  - HPCI TYPE
- Enterprise Information System Compatibility
  - SYSTEM ID
- External Information System Compatibility
  - SYSTEM ID
- Adaptability to Information Systems
- Interface Technology Compatibility
  - INTERFACE TECHNOLOGY
- Interface Support
  - INTERFACE TYPE
- API Support
  - API TYPE

Community of Interest and Teaming Support
- Collaboration Support
- Consortium Asset Member Access
- Partner Ecosystem Access Feature
- Hybrid Public-Private Layered Model Security
- Decision-Making Support Capability
  - DECISION TYPE
- Annotation Feature
- Team Identification Feature
- Learning Sharing Feature
- Issues Submission and Tracking Feature

Fit to User and Use
- Supported User Population
  - TARGET GROUP
- User Interface Capability
  - UI CAPABILITY
- User Experience Feature
  - EXPERIENCE TYPE
  - Satisfaction
- My Customizable Repository
- User Experience Feedback Support
- User Standards Compliance
  - STANDARDS AREA
- Cost of Use
- User Education Feature
  - EDUCATIONAL CAPABILITY
- Built In Guidance and Education
- Example Models
- Assimilation AIds
- System Performance and Capacity
  - RESPONSE CLASS
  - Response Time
  - Sessions Capacity
- System Reliability and Availability
  - SERVICE TYPE
  - Availability
  - MTBF
  - MTTR

Model Application Transaction Support
- Modeled System Life Cycle Support Application
  - LIFE CYCLE PROCESS SUPPORTED (ISO15288)
    - *Business, Mission Analysis*
    - *Stakeholder Needs, Requirements Defn*
    - *System Requirements Definition*
    - *Requirements Validation*
    - *Architecture Definition*
    - *Design Definition*
    - *Verification by Analysis & Simulation*
    - *System Analysis*
    - *Implementation*
    - *Integration*
    - *Verification by Test*
    - *Solution Validation*
    - *Acquisition*
    - *Supply*
    - *Project Planning*
    - *Project Assessment & Control*
    - *Decision Management*
    - *Configuration Management*
    - *Risk Management*
    - *Quality Assurance Process*
    - *Information Management*
    - *Measurement*
    - *Project Portfolio Management*
    - *Infrastructure Management*
    - *Life Cycle Model Management*
    - *Human Resource Management*
    - *Quality Management*
    - *Knowledge Management Process*
- Model Application Development
  - DEVEL CAPABILITY
- Cross-Domain Enterprise Model Support
  - Domain
    - *Application Domain*
    - *Manufacturing Domain*
    - *Distribution Domain*
    - *Sustainment Domain*
    - *Innovation Domain*
    - *Marketing Domain*
- Model-Based Artifact Generation Feature
- Supply Chain Reverse Auction
- Repository Transactions Support
  - TRANSACTION TYPE
- Regulated Domain Framework
- External System Transactions Integration
  - TRANSACTION TYPE
  - External System
- Advanced Decision-Making Support
- Risk Visualization
- Behavior Visualization
- Extraction Methods
- Entry Methods
- Accessibility
- Collaboration Merge vs. Git Hub

Model-Based Pattern Support
- MBSE Pattern Management Feature
- Configurable Model Pattern Library
- Pattern Configuration Generation
- Pattern Archetype Model Support
- Domain Library Support
  - DOMAIN
- Trusted Configurable Pattern
- System Framework Integration for Computational Models

Model Life Cycle Management
- Model Configuration Item Identification and Management
- Change Managed Content
- Model Life Cycle Governance
- Model Versioning and Configuration Management
  - CM CAPABILITY TYPE
- Model Planning and Lifecycle Management Framework
- Model Life Cycle Management
  - LC MANAGEMENT CAPABILITY
- Model Maintenance Event Service
- Model Provenance Management

Repository System Sustainability
- System Security Management Capability
  - SM CAPABILITY
- System Fault Management Capability
  - FM CAPABILITY
- System Configuration Management Capability
  - CM CAPABILITY
- System Accounting Management Capability
  - AM CAPABILITY
- System Performance Management Capability
  - PM CAPABILITY

Configurable Repository Deployment
- Private Intranet Configuration
- Shared Community Configuration
- COTS Platform Support
- Cloud Service Configuration
- Hybrid Configuration

Repository Release Roadmap
- Repository Release Deliverability
  - REPOSITORY RELEASE
  - Availability Date
  - Development Cost
  - Development Risk

Legend:
- STAKEHOLDER FEATURE
  - FEATURE PK ATTRIBUTE
    - *Selectable Value Option*
    - *Selectable Value Option*
    - *Selectable Value Option*
  - Other Feature Attribute
  - Other Feature Attribute

Notes:
- This pattern is a specialization of the S*Repository Pattern.
- A specific repository configuration may have a populated subset of the features of this pattern framework.
- This is a Feature pattern describing the trade space for such repositories, but the appearance of a Feature in the above model is no guarantee that it can be supported in an implemented system, unless it appears in the configured Features for that system.

V4I Model Repository (Digital Commons) Pattern Features		Systematica™ Do more with less
Version: 1.2.8	Date: 30 Oct 2017	Drawn By: ICTT System Sciences