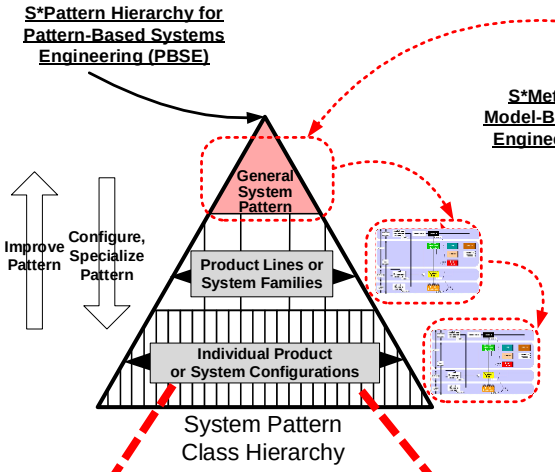
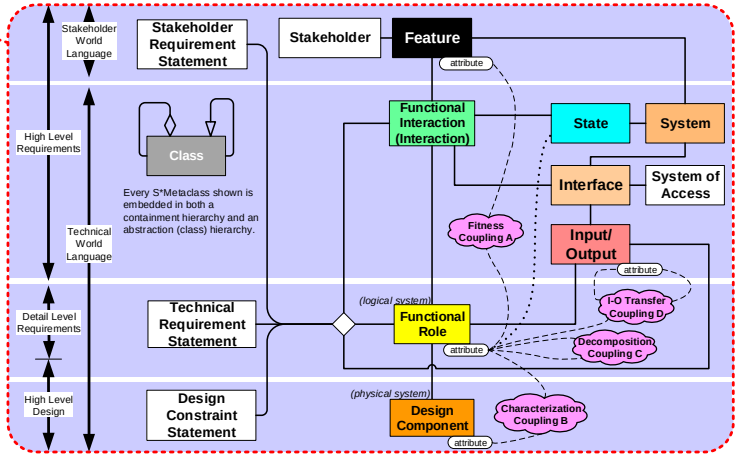
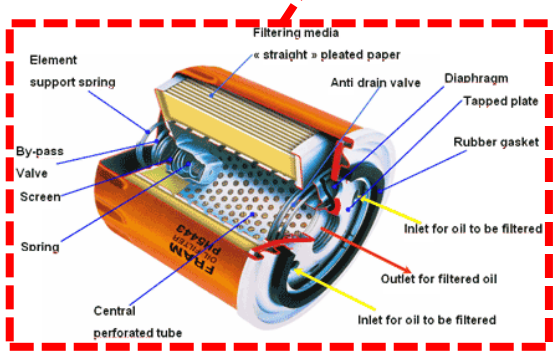
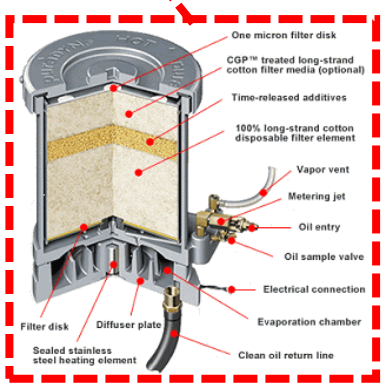
S*MBSE Patterns: A small scale example

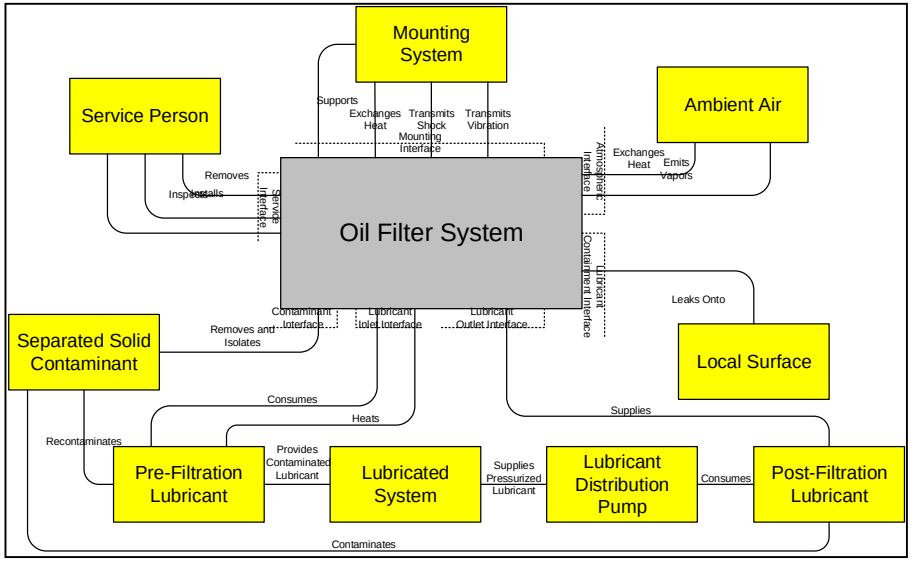




S*Metamodel informal summary pedagogical diagram
(formal S*Metamodel includes additional details.)



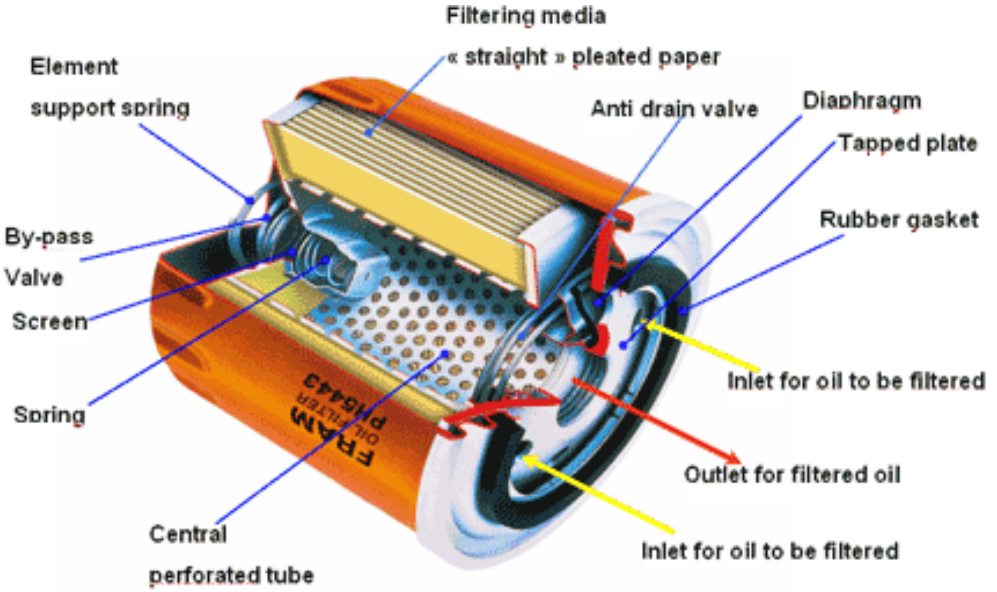




ICTT System Sciences®
Understand your systems.

Contents

Introduction

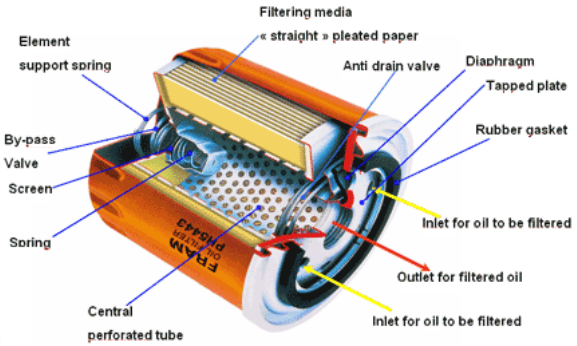


- This material illustrates a simple (lubricating oil filtration) system MBSE S*Pattern, with (portable) S*Model data shown in the "pattern starter kit", SE Patterns Workbook.
- Other material shows the same (portable) oil filter MBSE pattern data in an OMG SysML® third party COTS tool.
- In general, S*Models and S*Patterns may be ported into any tooling that is enabled with an S*Mapping from ICTT System Sciences.

Multiple configurations allow a product line family to cover the differing needs associated with different customer groups, applications, market segments, regulations, and other variant drivers.

Family of Systems: Filter Configurations

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

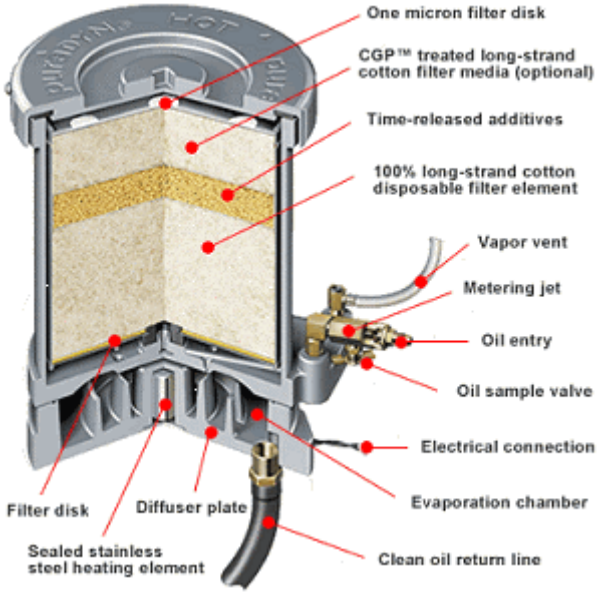


Paper
Filter Media

Synthetic
Filter Media

Stainless Steel
Filter Media

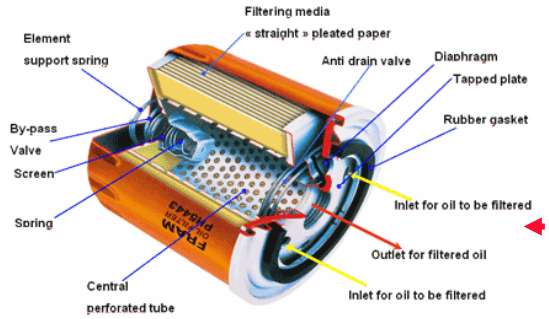
Architecture 2: Wound Filtration Fiber, Flow Orthogonal to Plane of Windings, Additive Impregnated



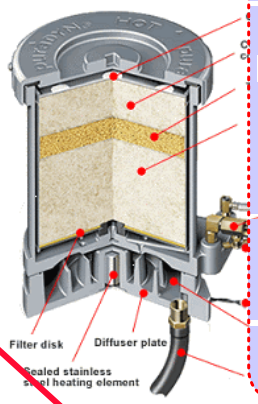
We'll see how the characteristics of general and specific oil filters are described by the S*Metamodel

Family of Systems: Filter Configurations

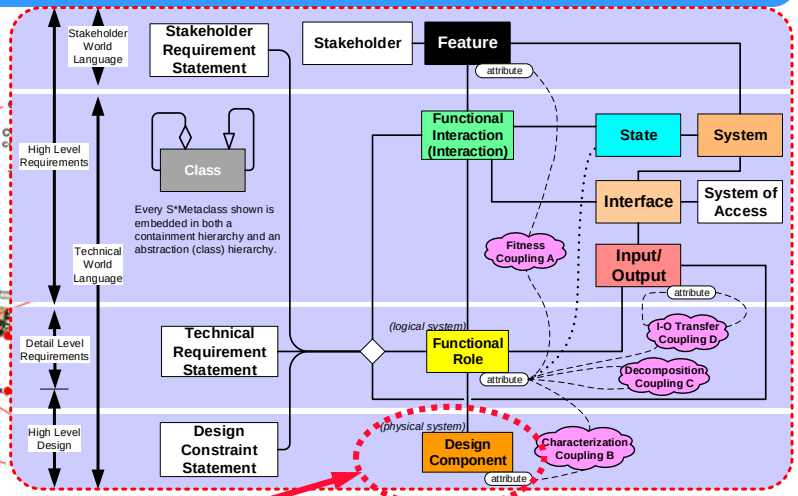
Architecture 1:



Architecture 2:



Different architectures



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

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

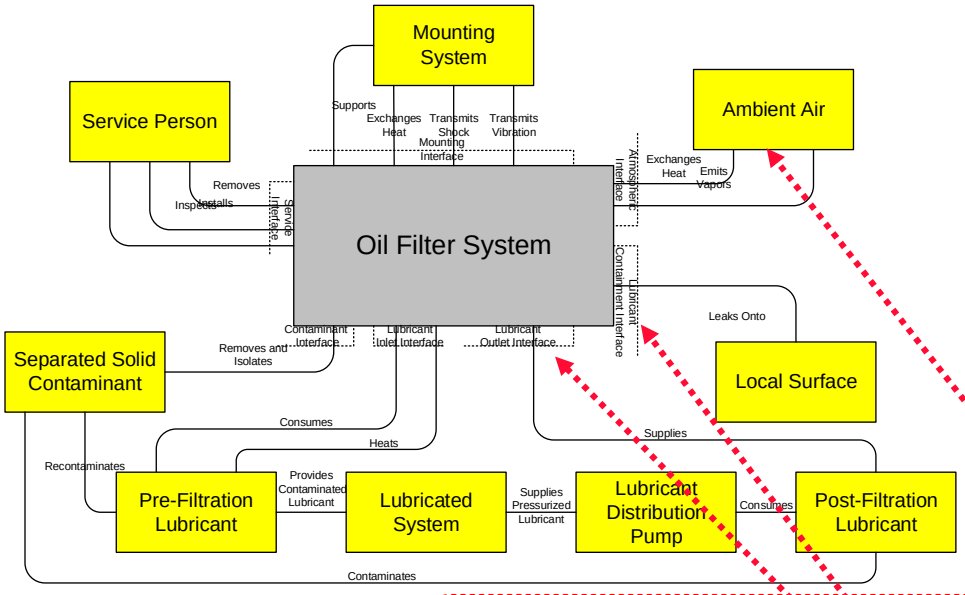
Attribute Tuning Loop (many times)

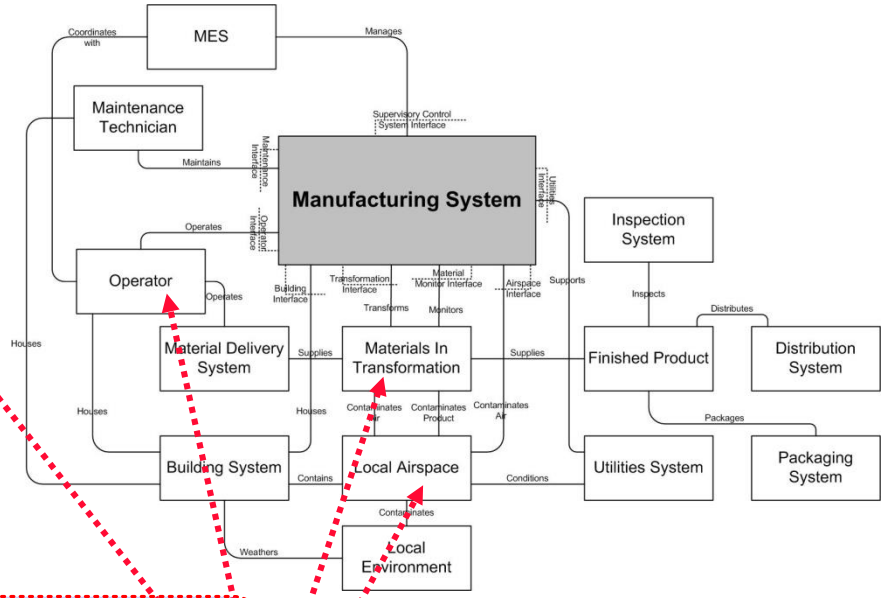
Setting / Adjusting Attribute Values

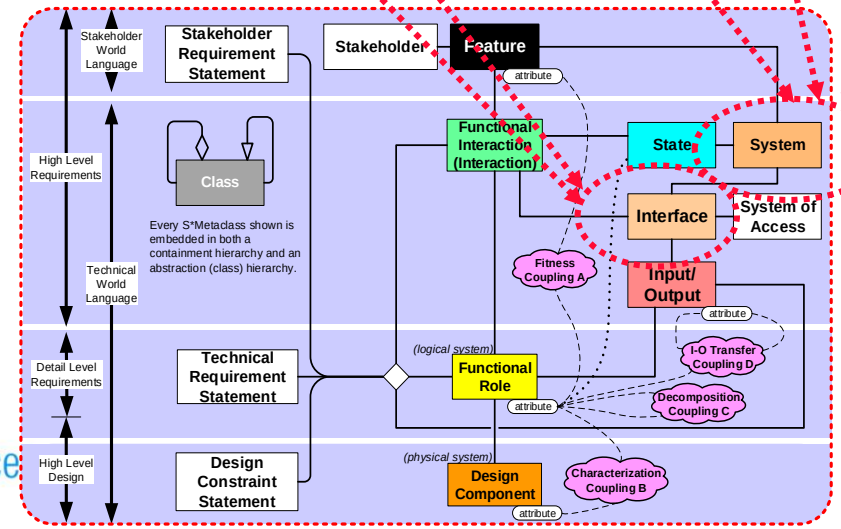
(See Attribute Coupling Model)

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







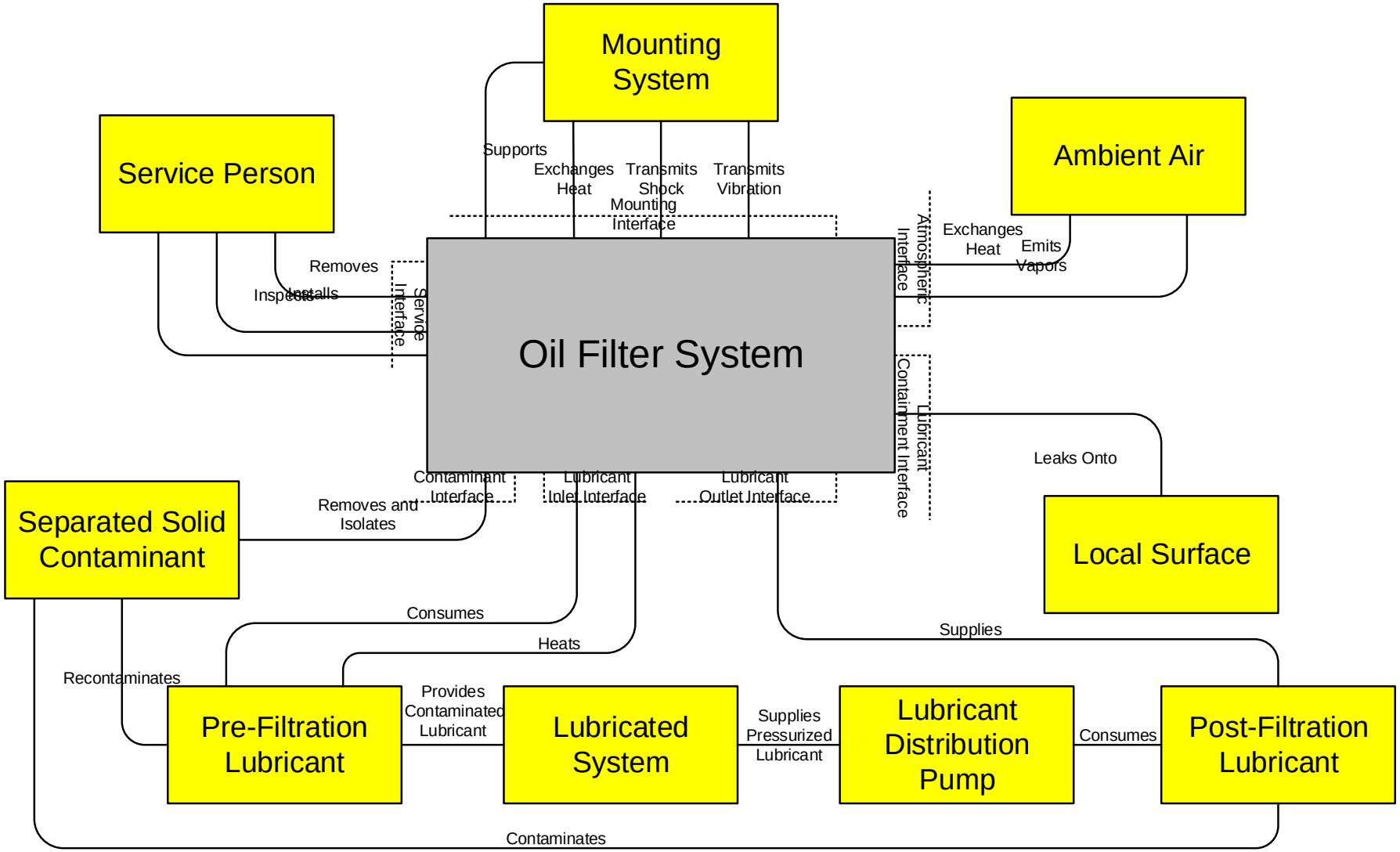
Product Application Domain Model

Manufacturing Domain Model

ICTT System Science

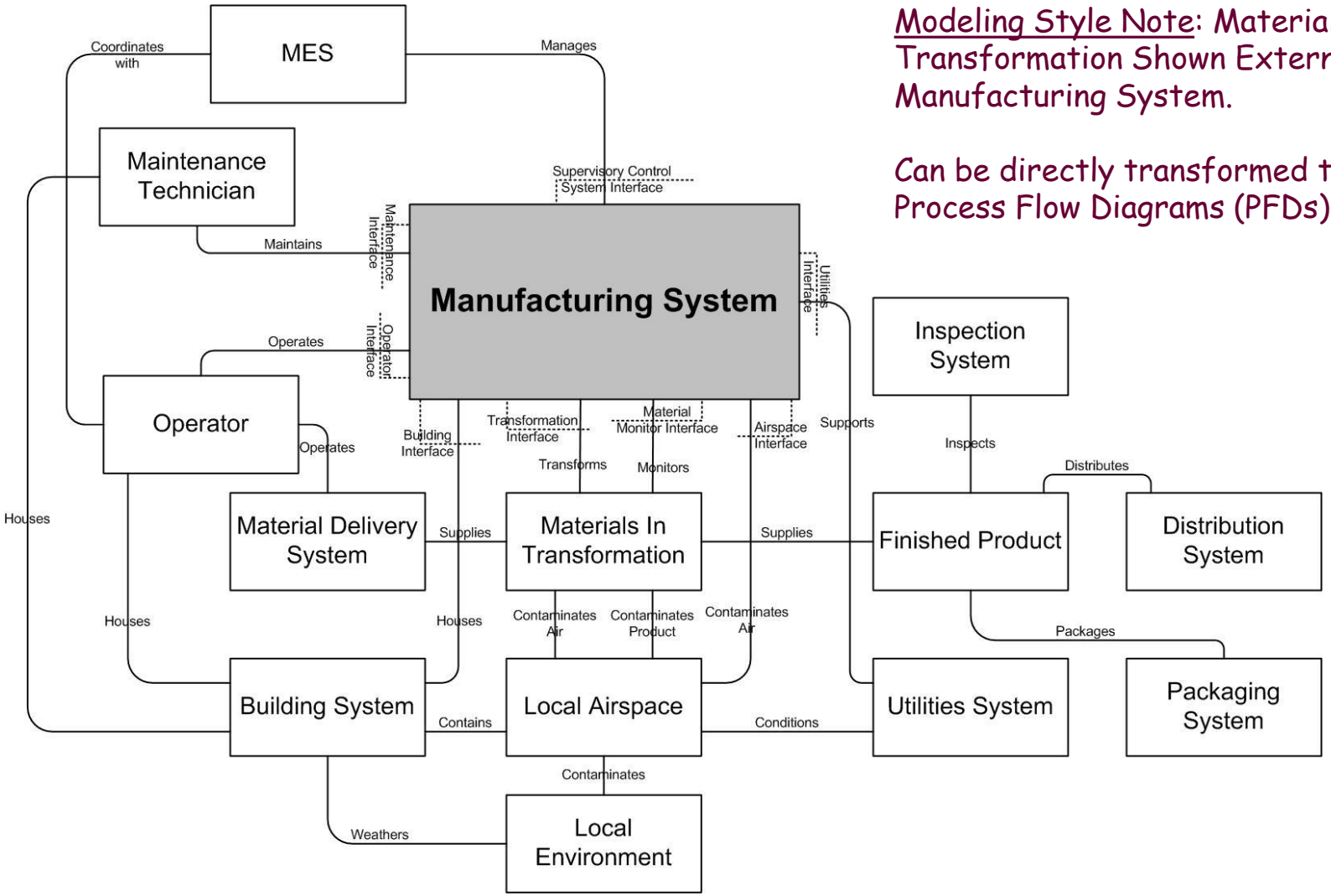
Domain Models show the external systems that interact with a Subject System over its domain life cycle. This defines the System Boundary, External Interfaces, Domain Relationships.

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

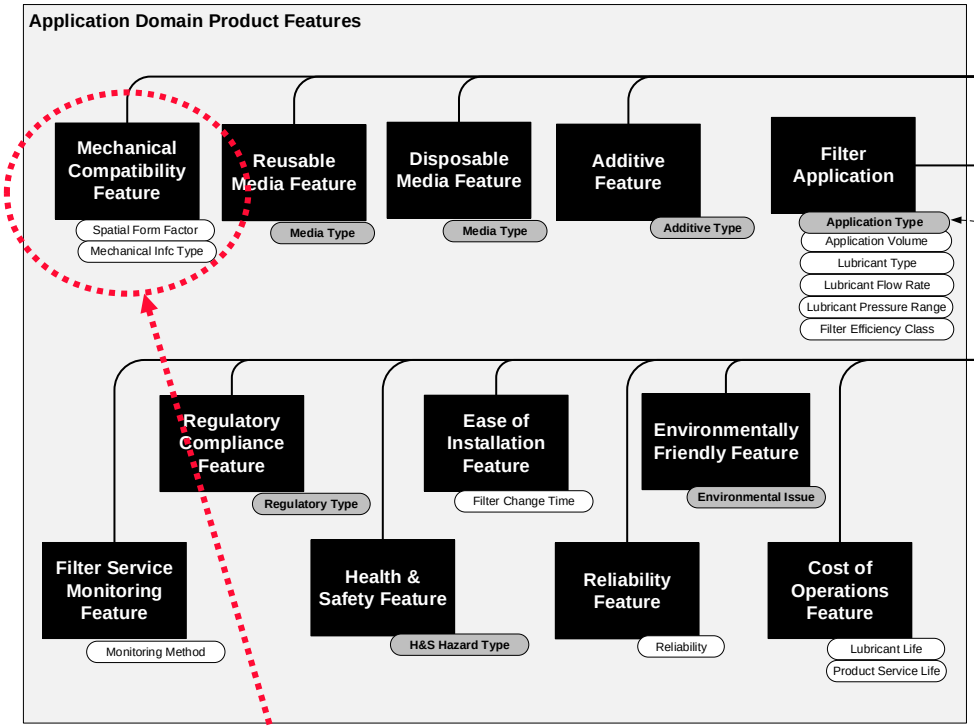


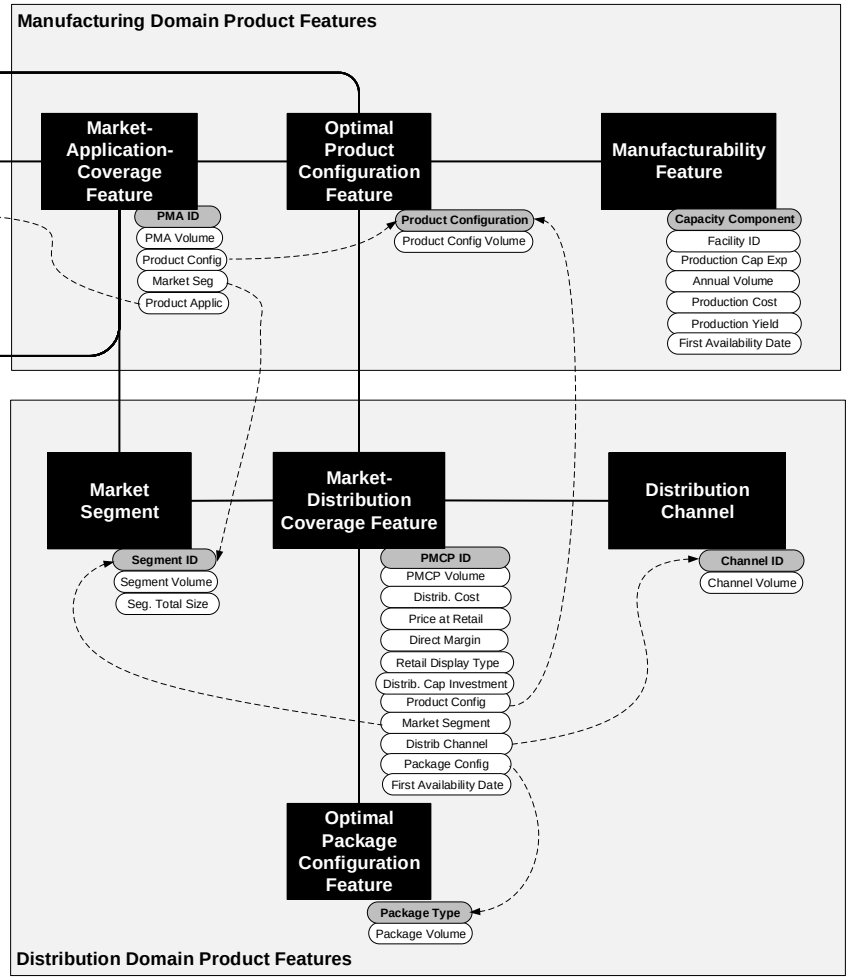
Modeling Style Note: Material In Transformation Shown External to Subject Manufacturing System.

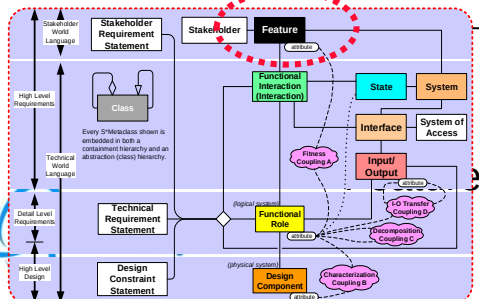
Can be directly transformed to/from Process Flow Diagrams (PFDs).

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.)

Stakeholder Features







e Overview Diagram

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

Microsoft Excel - Oil Filter Pattern V1.1.1.xls

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

	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	Namec
3	**Engine Lubricant Filtration Feature**			Lubricant Type		The type of lubricating fluid to be used.	N/A	0	Namec
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	Namec
5	**Engine Lubricant Filtration Feature**			Lubricant Pressure Range		The amount of hydraulic pressure under which the lubricant will circulate.	N/A	High, Medium, Low	Namec
6	**Engine Lubricant Filtration Feature**			Filter Efficiency Class		The range of filtration efficiency provided by the filter	N/A	0	Namec
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	Namec
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	Namec
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	

Menu / Change History / Options / Wkbk Issues / Stakeholders / Advocates / Stakeholder-Advocate / Stakeholder Needs / **Features** / Feature Attributes / Feature-

Ready

Four key uses of Features

- Stakeholder value, trade space, optimization, rationale
- Risk management (all risks are risks to Features)
- FMEA (later section)
- Partitioning of product line space (later section)

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

Microsoft Excel - Oil Filter Pattern V1.1.1.xls

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3	**Engine Lubricant Filtration Feature**			Lubricant Type		The type of lubricating fluid to be used.	N/A	0
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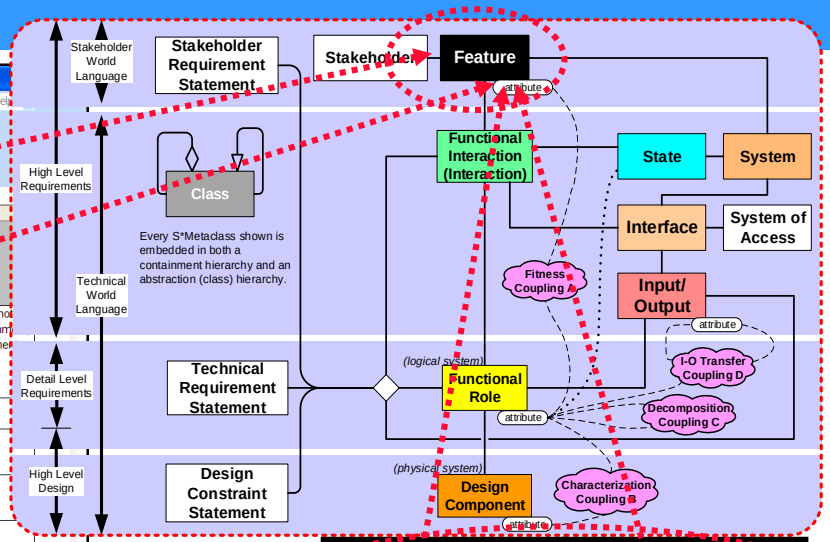
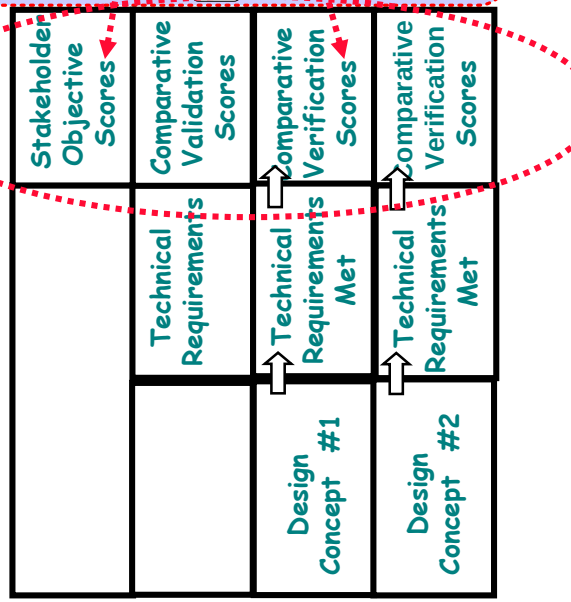
6	**Engine Lubricant Filtration Feature**			Filter Efficiency Class		The range of filtration efficiency provided by the filter	N/A	0
7	**Mechanical Compatiblity Feature**	Mandatory	The feature of being compatible in form factor and mechanical interface with the system in which the system will be installed.	Mechanical Interface Type		The mechanical form of an interface.	N/A	0
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
	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	N/A	Standard, Long Life





Configuration Score Sheet

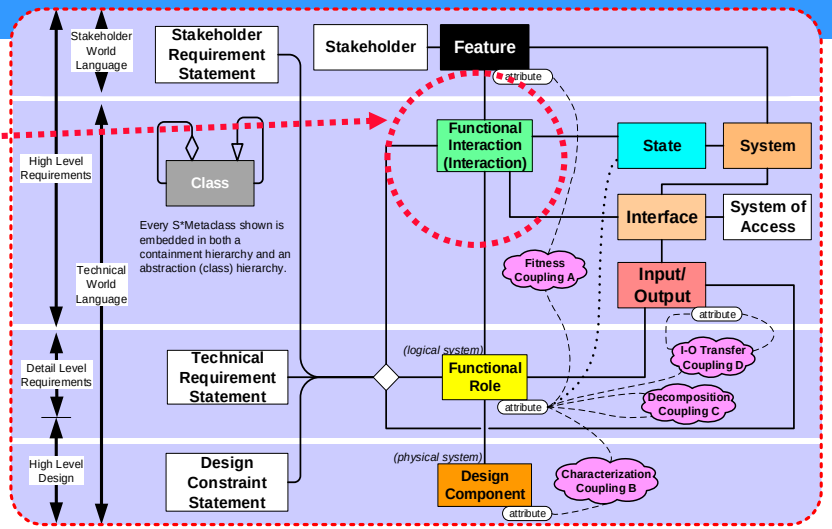
Alternate designs, different configurations, and technology generations are all ultimately "Scored" in lower-dimension trade-off space defined by the Stakeholder Feature Attributes.

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

An Interaction is an exchange, between two or more system components, of force, energy, material, or information, resulting in component state changes.

Functional Interactions

- Store Packaged Product
- Transport Packaged Product
- Identify Packaged Product
- Display Packaged Product
- Purchase Packaged Product
- Install Filter
- Filter Lubricant
- Prevent Lubricant Leakage
- Transmit Shock & Vibration
- Remove Filter
- Store Disposed Product
- Pre-Process Disposed Product
- Recycle Disposed Product
- Destroy Disposed Product
- Decompose Disposed Product

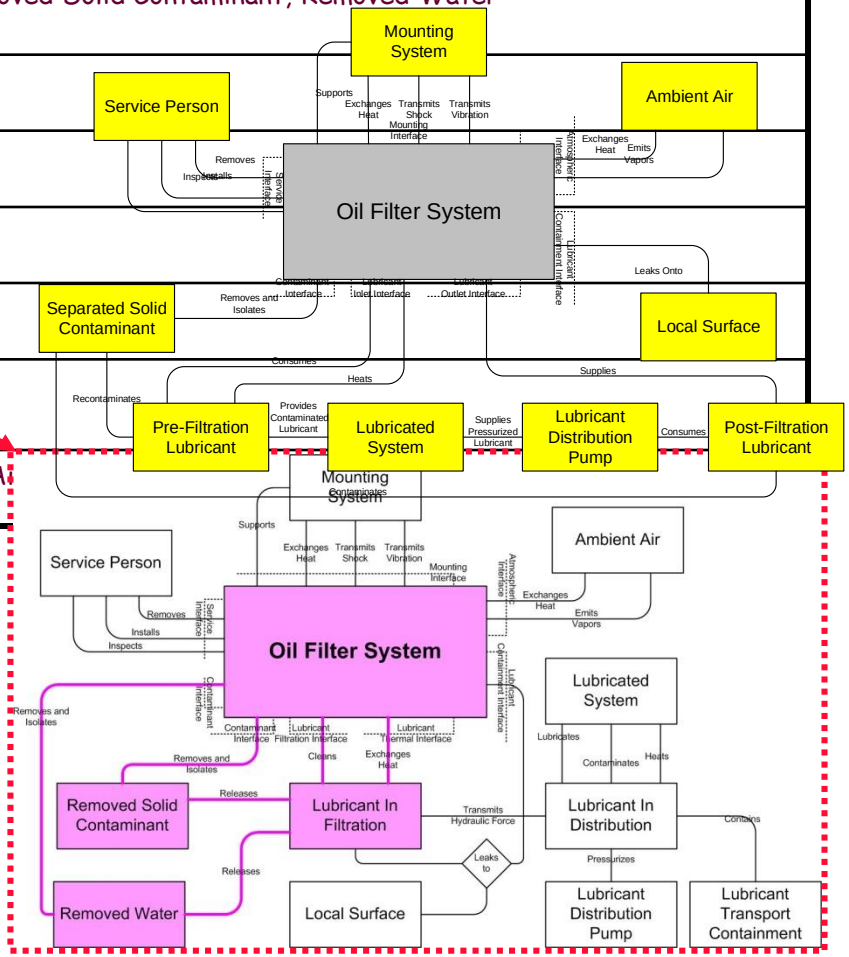


ICTT System Sciences

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 A

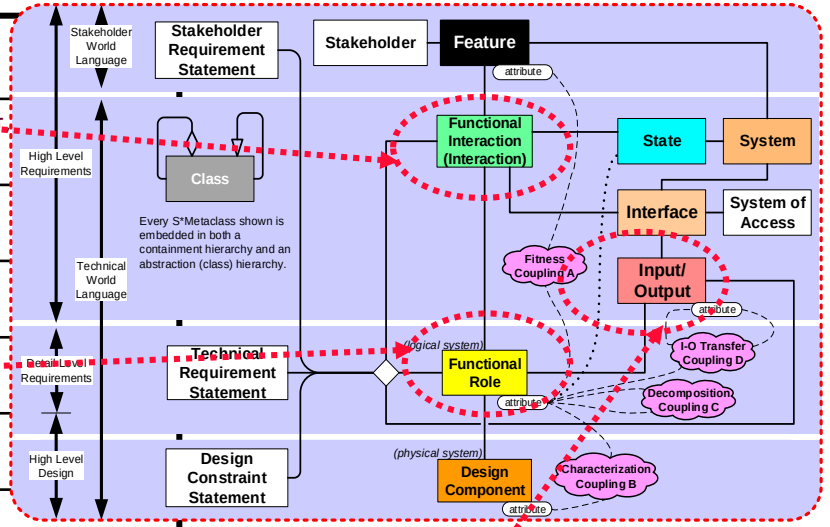


Every system directly interacting with the Subject System (Oil Filter System) contributes to its Requirements.

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

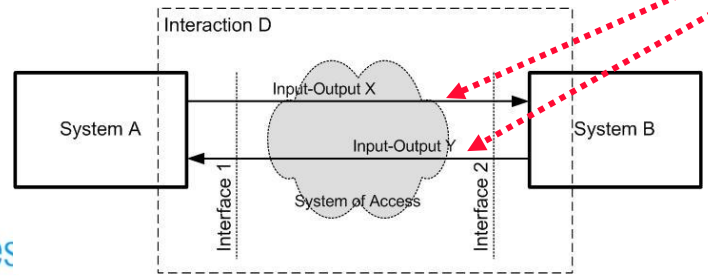
Functional Interaction	Functional Roles
Filter Lubricant	Lubricant in Filtration, Oil Filter System, Removed Solid Contaminant, Water
Change Filter	Service Person, Filter
Monitor Filter	Filter, Monitor & Control System
Prevent Vapor Leakage	Lubricant, Vapor, Filter, Atmosphere
Prevent Lubricant Leakage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



Input/Outputs exchanged during these interactions are:

- Energy
- Force
- Mass
- Information

Interactions involve two or more systems.

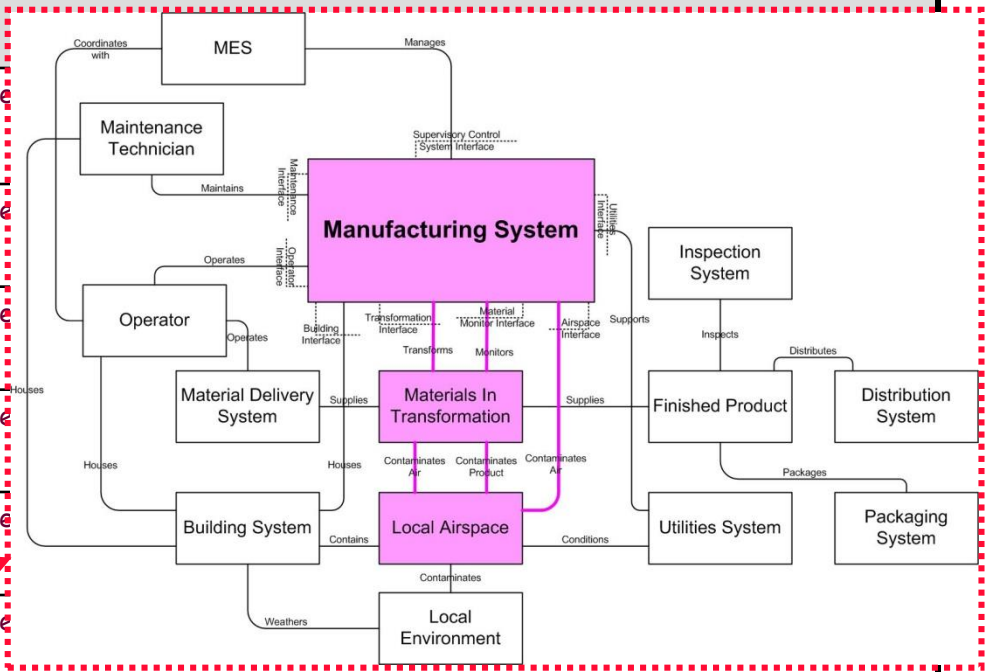


ICTT System Sciences

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

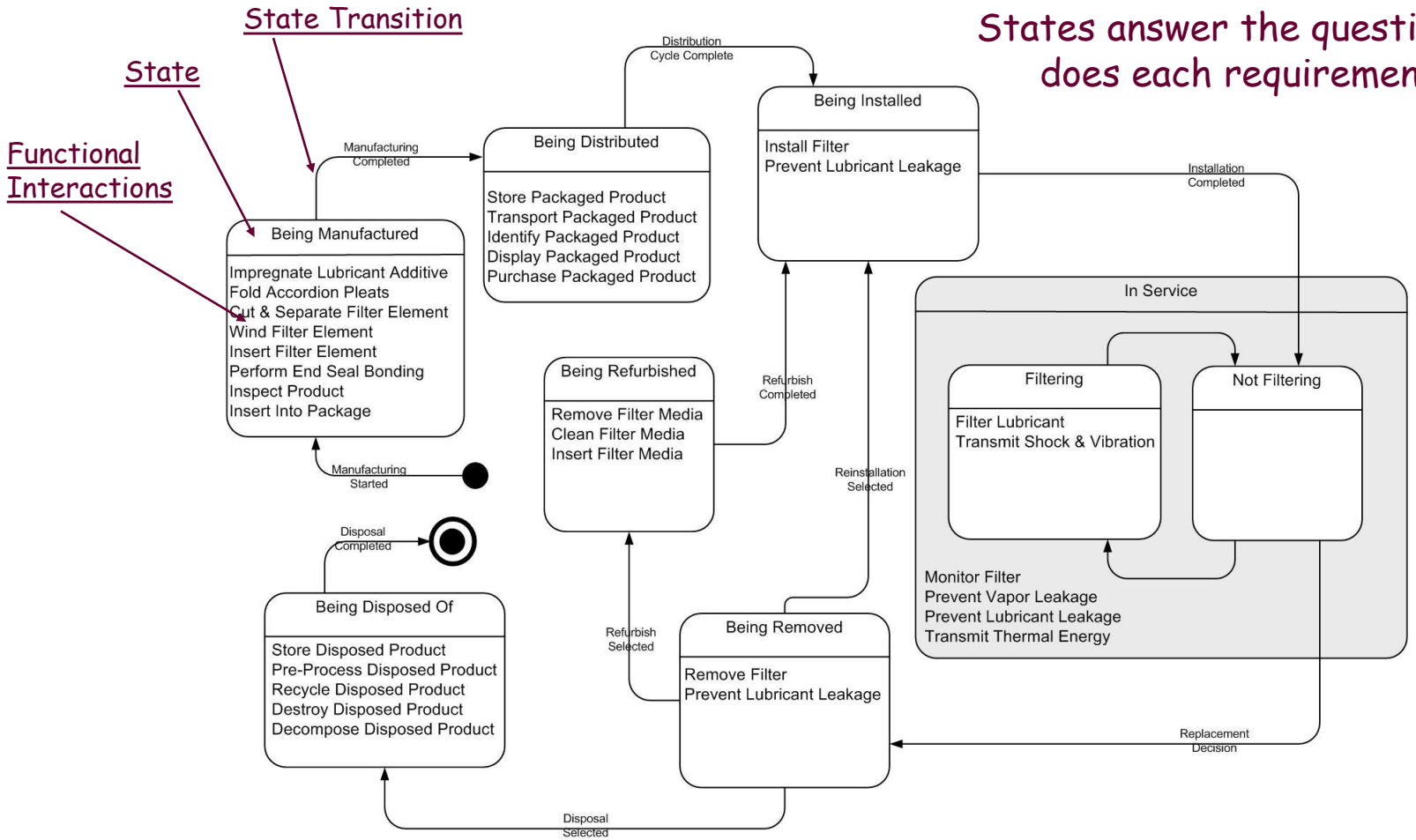


Later "drilled down" in Detail Level Requirements Model, to obtain Requirements Statements.

ICTT System Sciences

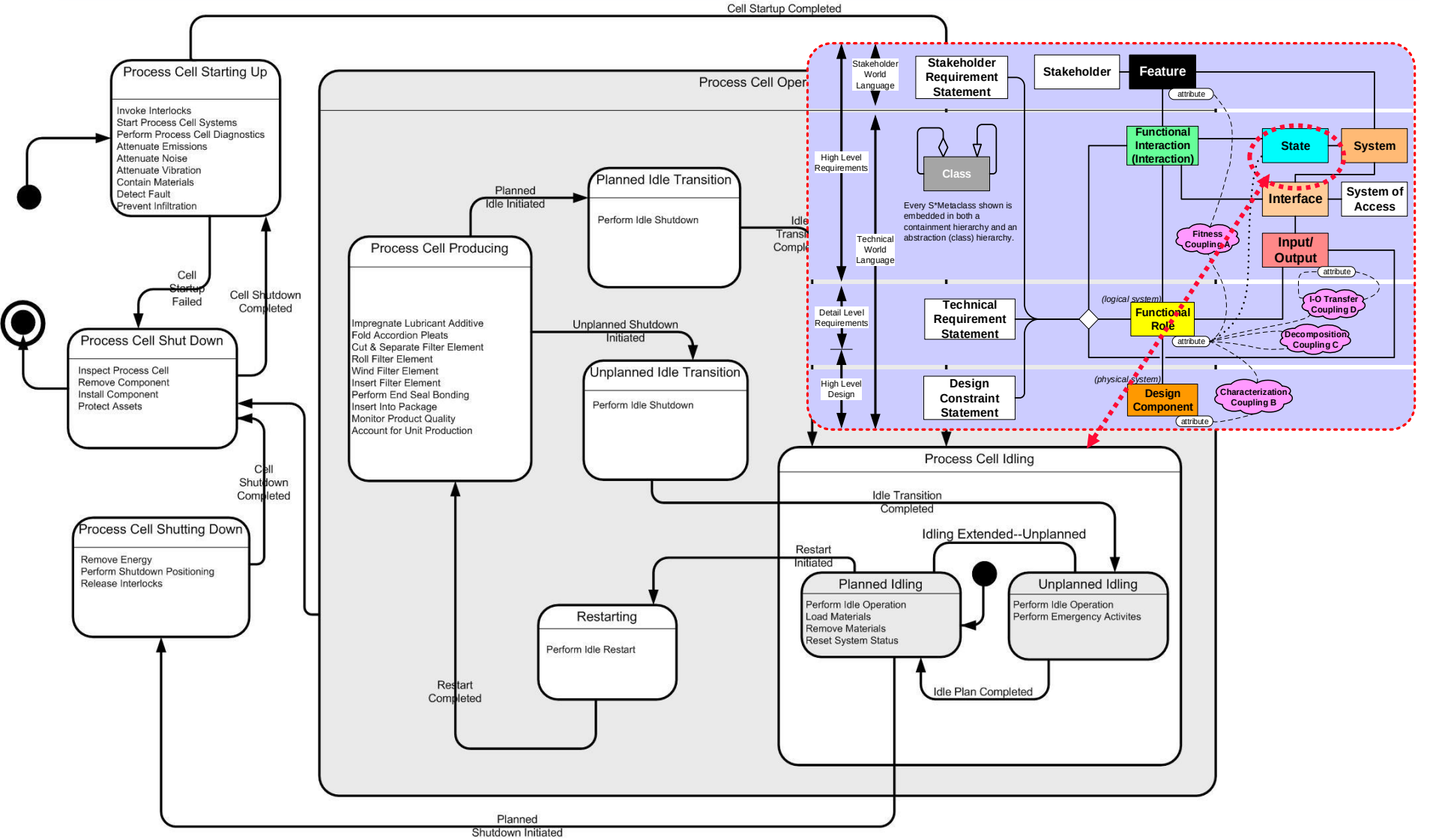
State Models directly address a key SE challenge by discovering and describing all Situations, Modes, or Use Cases (environmental states) that a Subject System will encounter. These are associated with Functional Interactions that lead directly to requirements. State Models can also describe Designs.

Product State Model



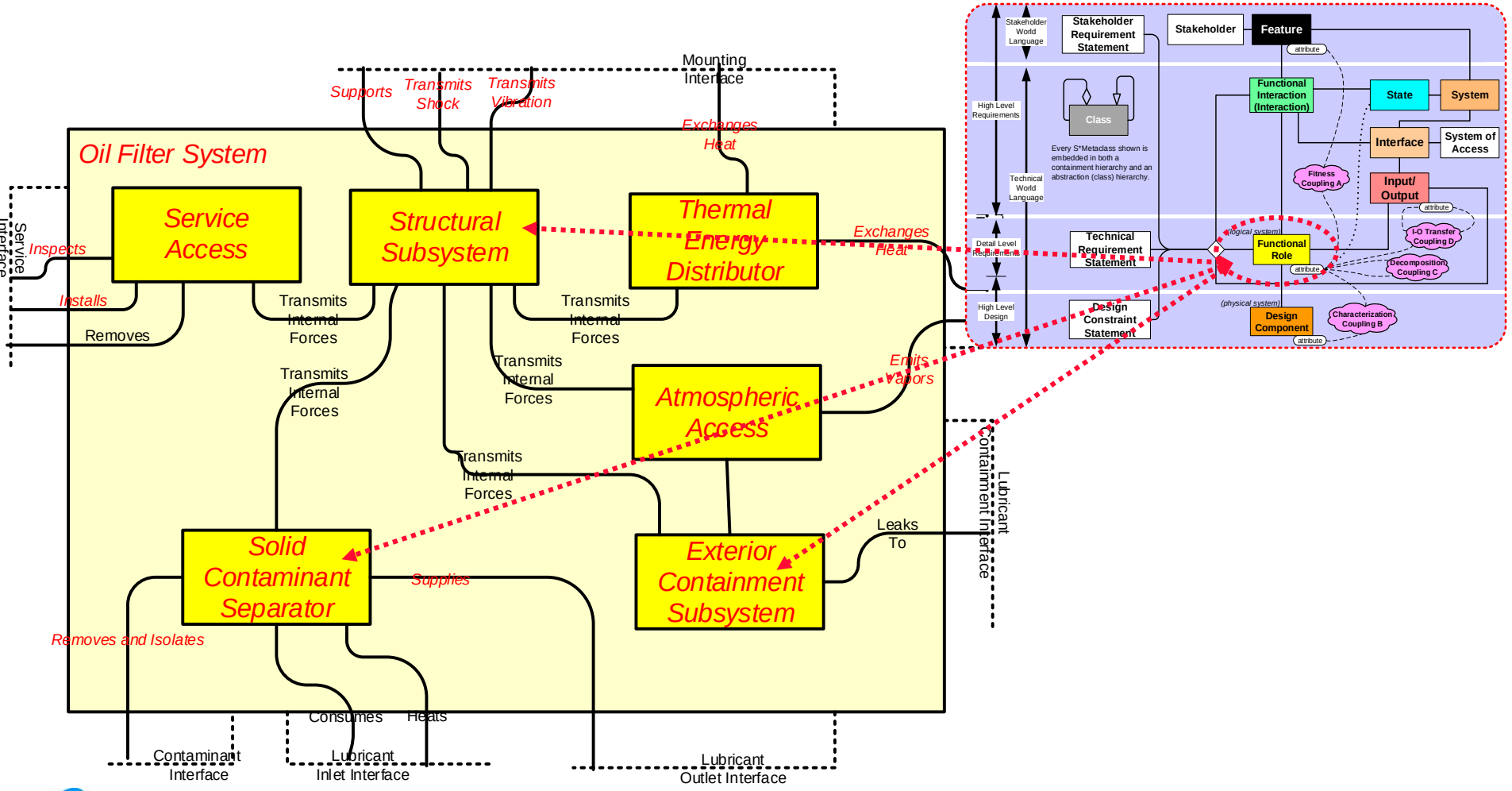
States are Situations (Modes, Use Cases, Phases) that will be encountered in the environment of a Subject System, in which it is required to meet certain requirements.

Manufacturing System State Model

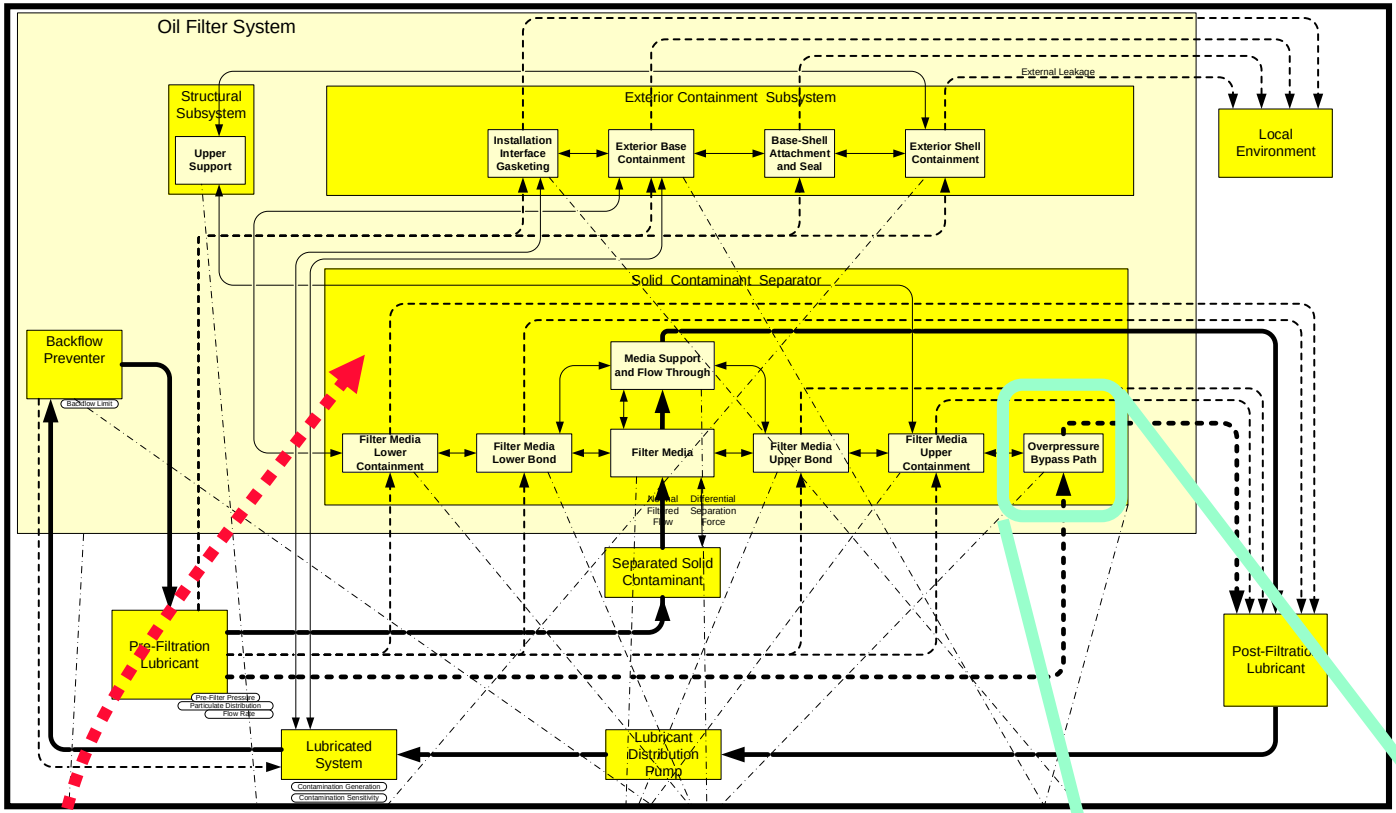


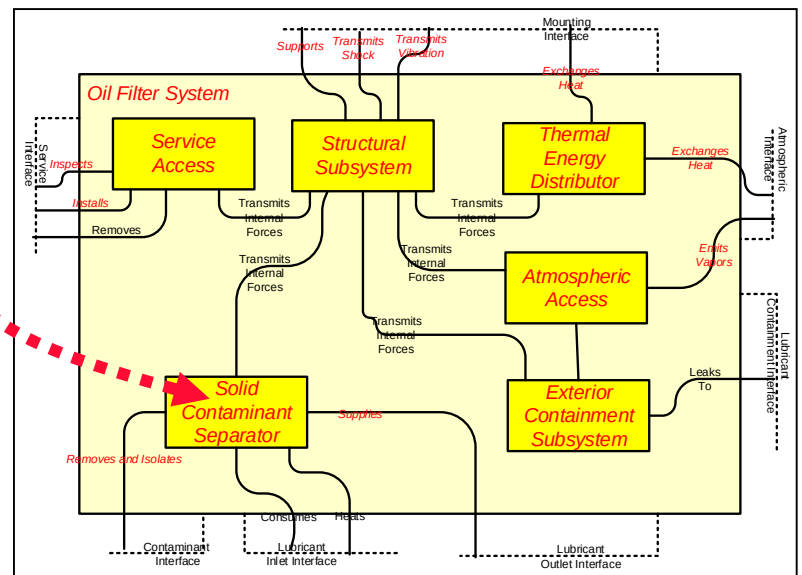
Logical Architecture Models directly address key SE challenges by partitioning the structure of requirements into Logical Roles independent of design, then address more SE challenges by stimulating design ideation and role allocation to physical designs and future technologies.

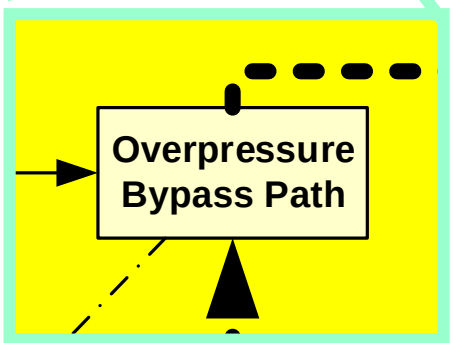
Product Logical Architecture Model



ICTT System Sciences



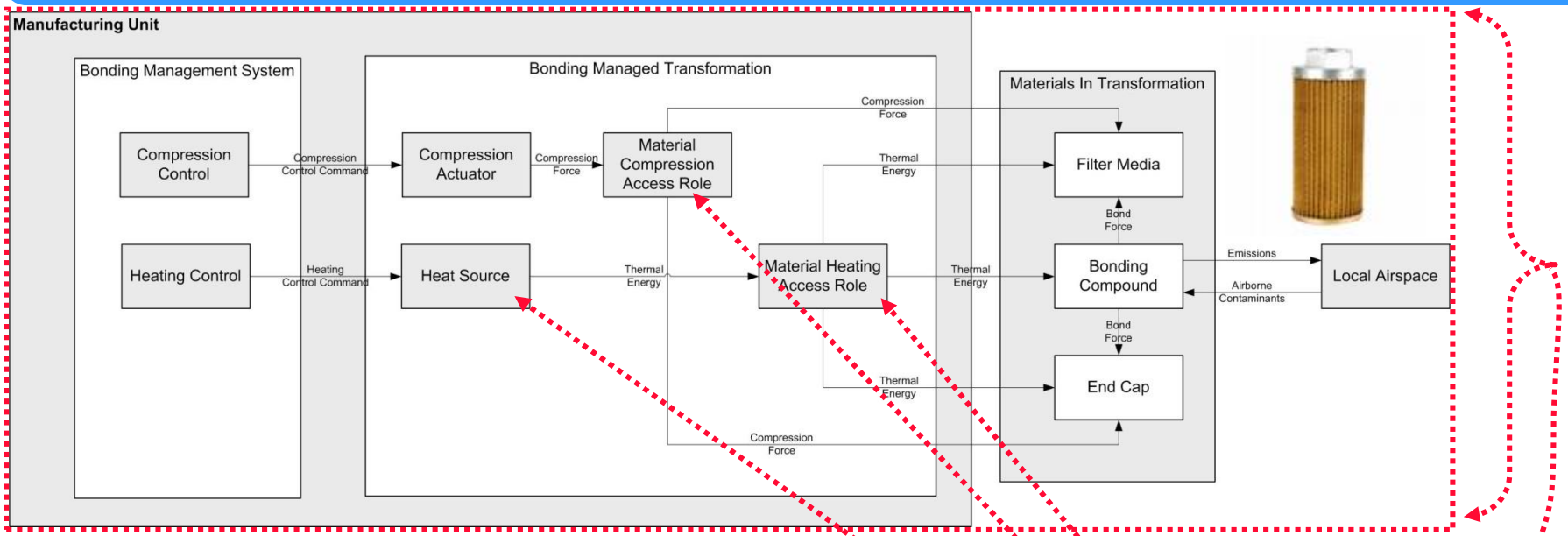




Allocating Functional Roles to Logical Subsystems

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

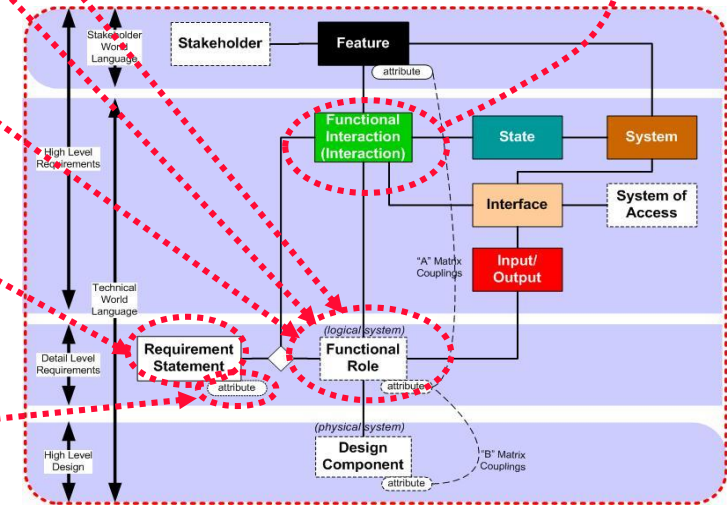


Benefit: This allows prose Requirements Statements to be viewed as Transfer Functions, greatly improving ability to audit regular detail requirements by embedding them in the Model:

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]."



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

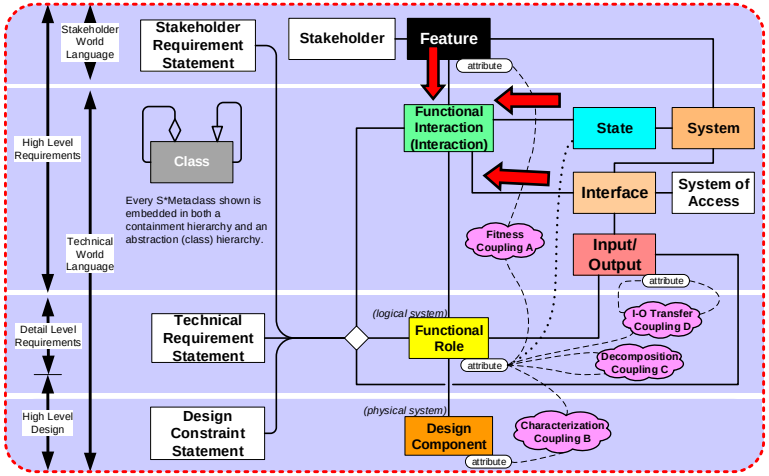
The three MBSE roads to finding all Requirements

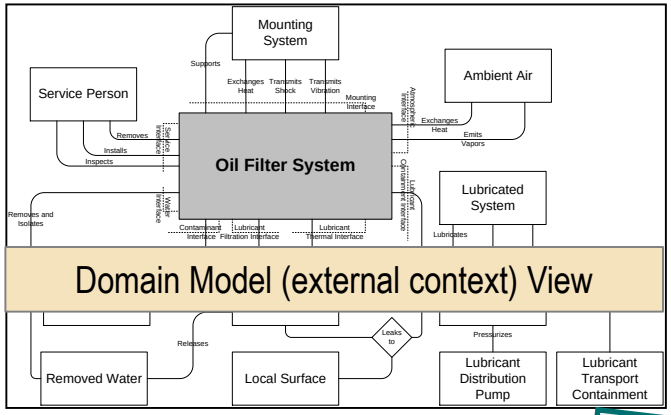
MBSE provides a powerful paradigm for discovering all the Interactions, and therefore all the system Functional and Non-Functional Requirements:

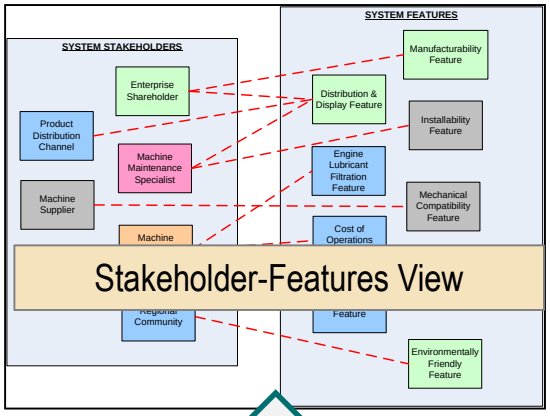
1. Domain Model: Find all the external Actors that interact with the system.
2. State Model: Find all the States (situations, modes, phases, use cases) that the system will encounter.
3. Feature Model: Find all the Features valued by Stakeholders.

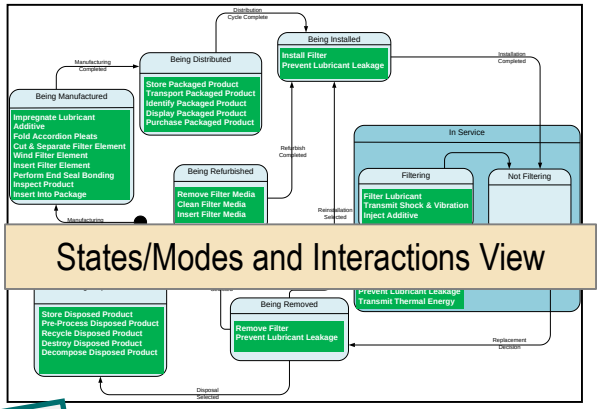
Benefit: These three (redundant) paths provide a higher-than-usual assurance of finding and validating all the Interactions and Requirements, which connect to each.

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

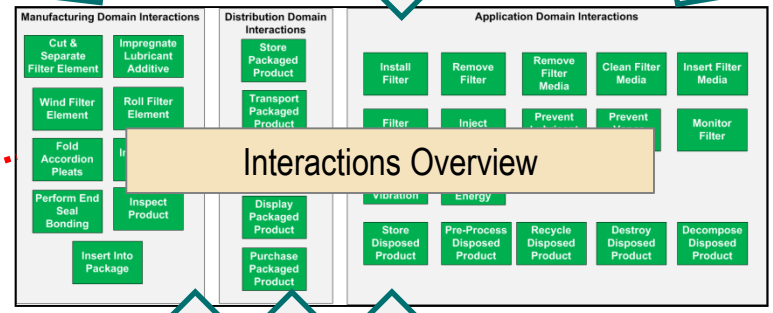






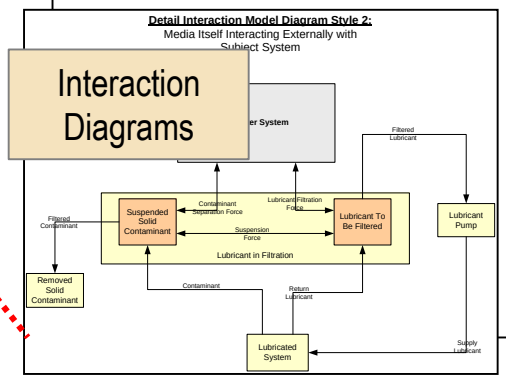


Discovering all the External Interactions



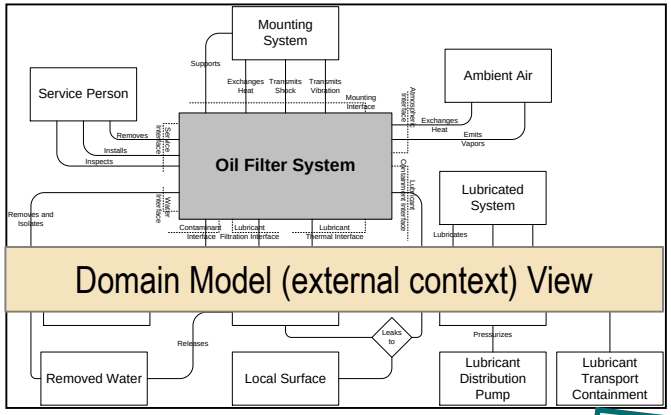
Selected views for use in discovering all the technical requirements and checking for completeness, consistency of same

Discovering all the Technical Requirements

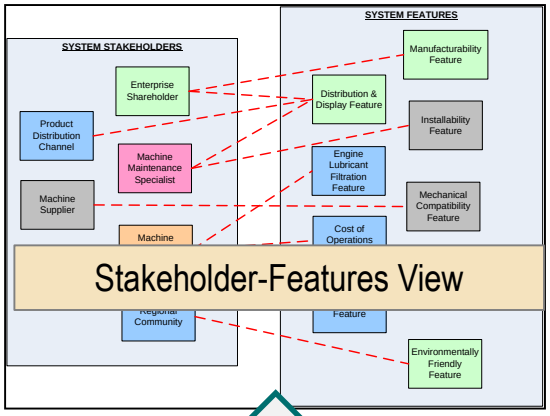


Interaction	Role	Requirement (Required or Assumed Behavior)
Filter Lubricant	Oil Filter System	For a Return Lubricant stream of [Lubricant Viscosity Range] and [Lubricant Pressure Range], the Oil Filter shall separate Filtered [illegible] output stream, [illegible] Distribution Profile].
Filter Lubricant	[illegible]	[illegible] viscosity within the
Filter Lubricant	[illegible] Pump	[illegible] within the [Lubricant
Install Filter	Oil Filter System	The Oil Filter shall be manually installable in ten minutes or less, using only a screwdriver.
Install Filter	Oil Filter System	The Oil Filter shall have installation instructions printed on its exterior surface, in English
Install Filter	Service Person	The Service Person shall have the visual acuity and hand strength of an average 40 year old adult.
Install Filter	Service Person	The Service Person shall be capable of reading English at the tenth grade level.

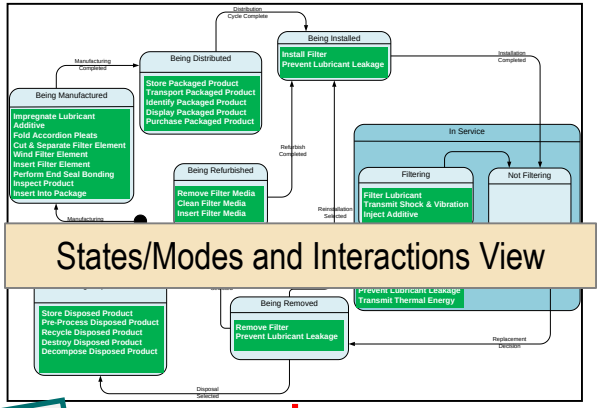
Technical Requirements



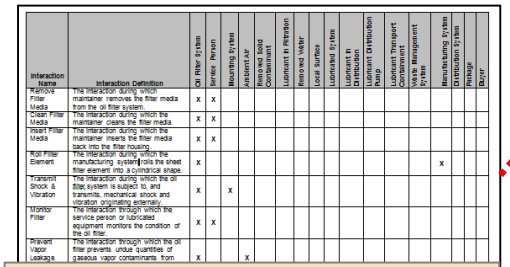
Domain Model (external context) View



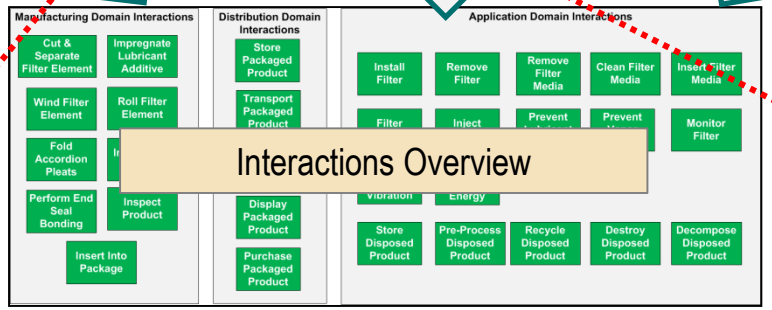
Stakeholder-Features View



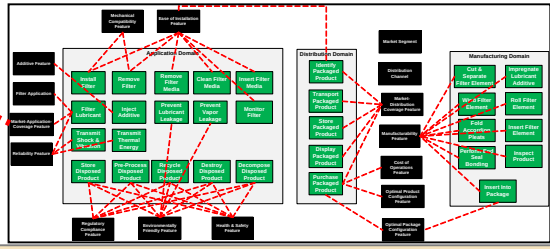
States/Modes and Interactions View



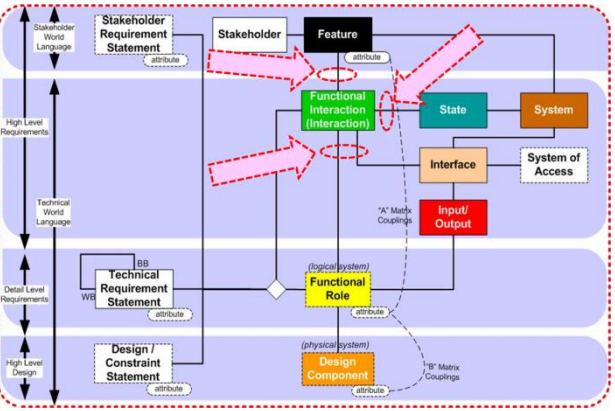
Interactions-Actors Associations



Interactions Overview



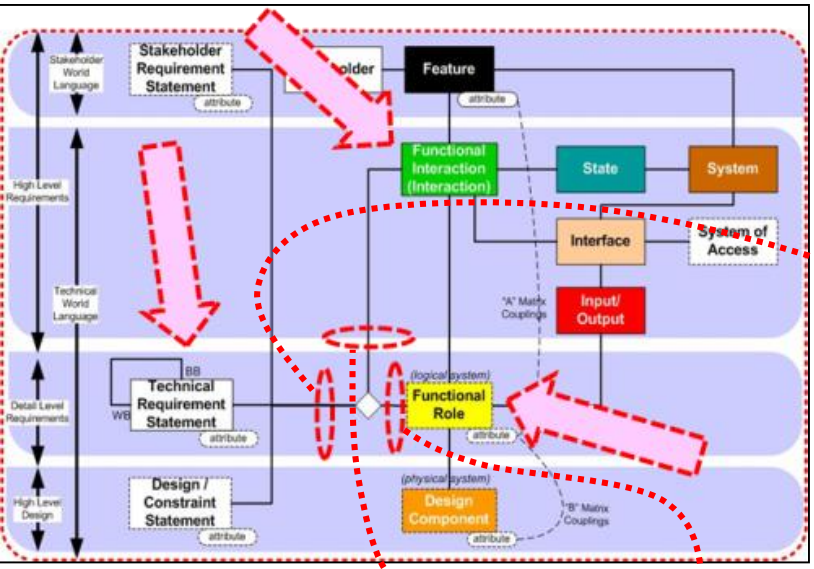
Features-Interactions Associations



Inherent Relational Checks of High Level Model Completeness / Consistency (Model Metrics)

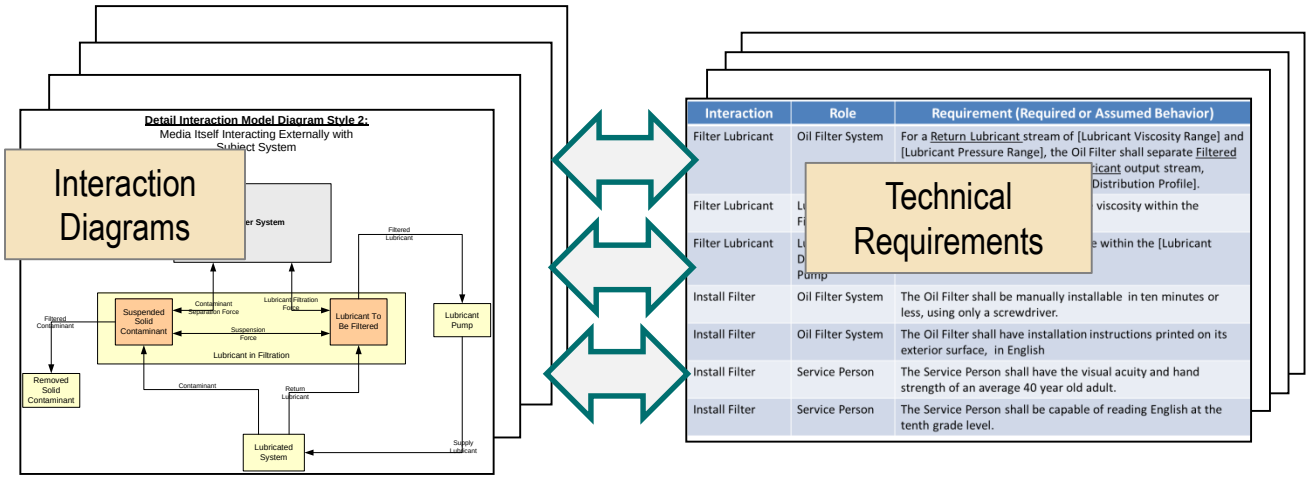
Three paths to the same Interactions

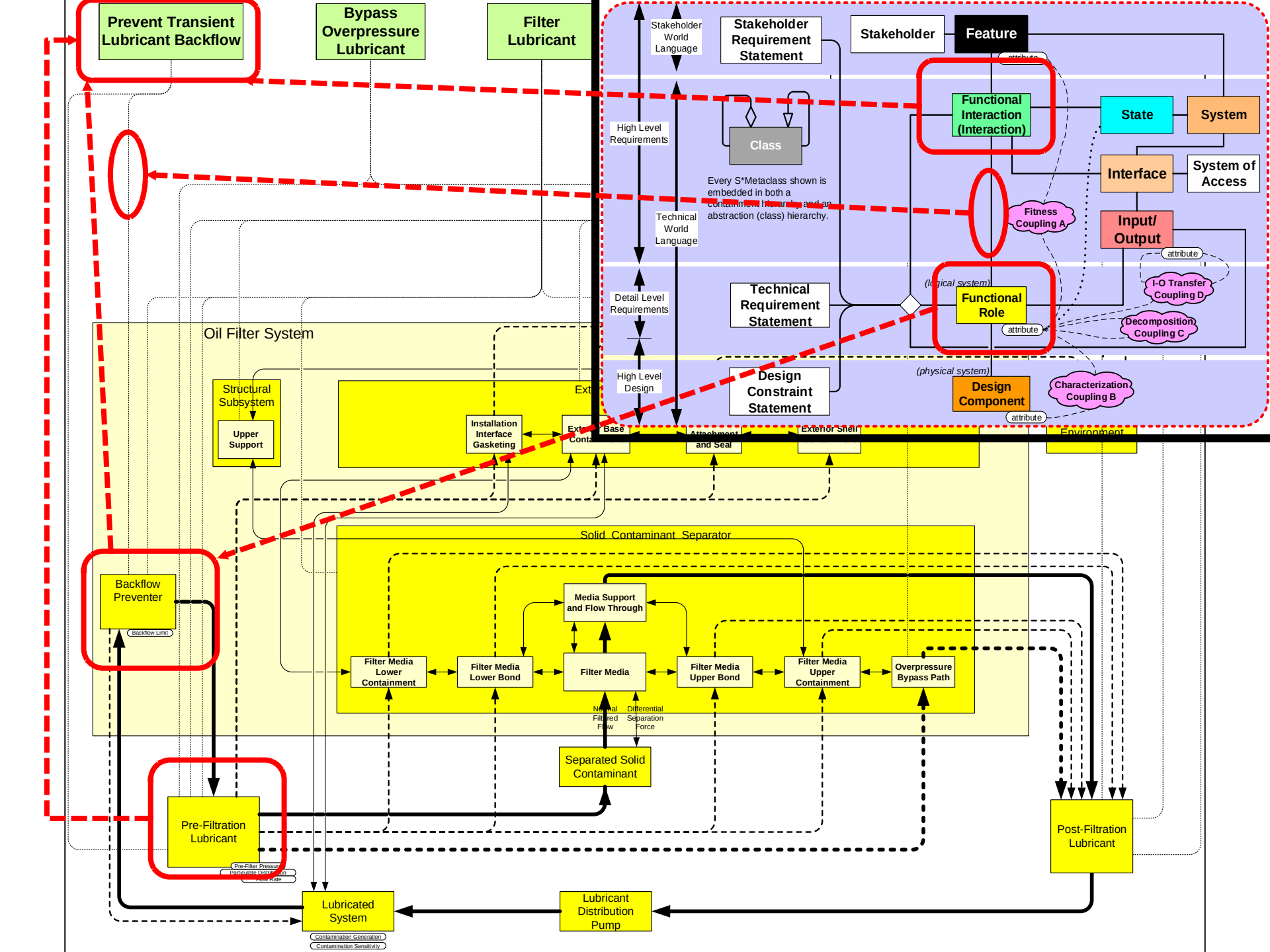
Inherent Relational Checks of Detail Level Model Completeness / Consistency (Model Metrics)



Requirements Statements are Transfer Functions

Interaction	Role	Requirement (Required or Assumed Behavior)
Filter Lubricant	Oil Filter System	For a Return Lubricant stream of [Lubricant Viscosity Range] and [Lubricant Pressure Range], the Oil Filter shall separate Filtered Contaminant particles from the Lubricant output stream, according to the [Filter Particle Size Distribution Profile].
Filter Lubricant	Lubricant in Filtration	The Lubricant in Filtration shall have viscosity within the [Lubricant Viscosity Range].
Filter Lubricant	Lubricant Distribution	The Pump shall maintain oil pressure within the [Lubricant Pressure Range]

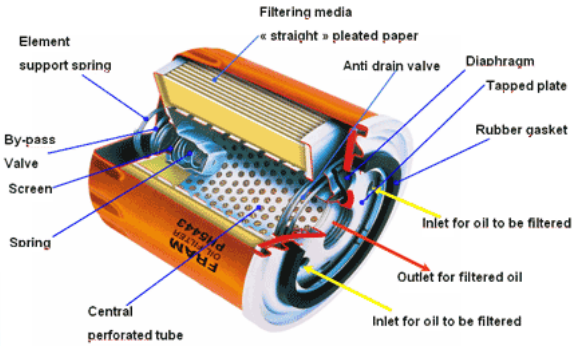



Prevent Transient Lubricant Backflow
Bypass Overpressure Lubricant
Filter Lubricant
Stakeholder World Language
Stakeholder Requirement Statement
Stakeholder
Feature
attribute
Functional Interaction (Interaction)
State
System
High Level Requirements
Class
Every S*Metaclass shown is embedded in both a containment hierarchy and an abstraction (class) hierarchy.
Interface
System of Access
Technical World Language
Fitness Coupling A
Input/ Output
attribute
I-O Transfer Coupling D
(logical system)
Detail Level Requirements
Technical Requirement Statement
Functional Role
attribute
Decomposition Coupling C
(physical system)
High Level Design
Design Constraint Statement
Design Component
Characterization Coupling B
attribute
Environment
Oil Filter System
Structural Subsystem
Upper Support
Installation Interface Gasketing
Base
Attachment and Seal
Exterior Shell
Solid Contaminant Separator
Backflow Preventer
Backflow Limit
Media Support and Flow Through
Filter Media Lower Containment
Filter Media Lower Bond
Filter Media
Filter Media Upper Bond
Filter Media Upper Containment
Overpressure Bypass Path
Normal Filtered Flow
Differential Separation Force
Separated Solid Contaminant
Pre-Filtration Lubricant
Pre-Filter Pressure
Particulate Distribution
Flow Rate
Post-Filtration Lubricant
Lubricated System
Contamination Generation
Contamination Sensitivity
Lubricant Distribution Pump

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

Product Physical Architectures

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

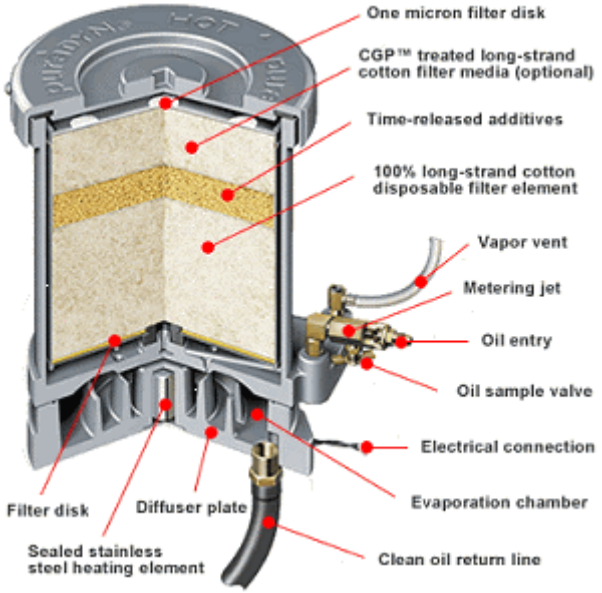


Paper
Filter Media

Synthetic
Filter Media

Stainless Steel
Filter Media

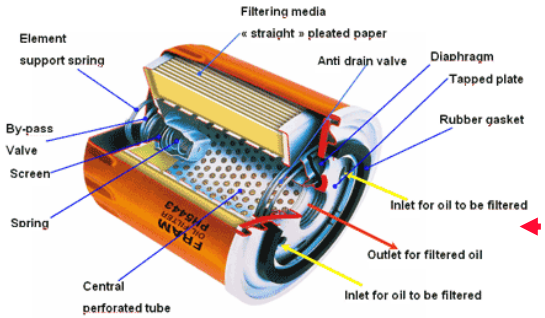
Architecture 2: Wound Filtration Fiber, Flow Orthogonal to Plane of Windings, Additive Impregnated



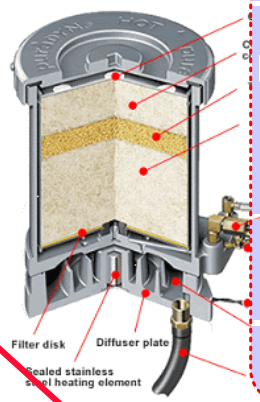
Physical Architecture describes the subject system's major physical components, their organization, and primary physical attributes.

Product Physical Architectures

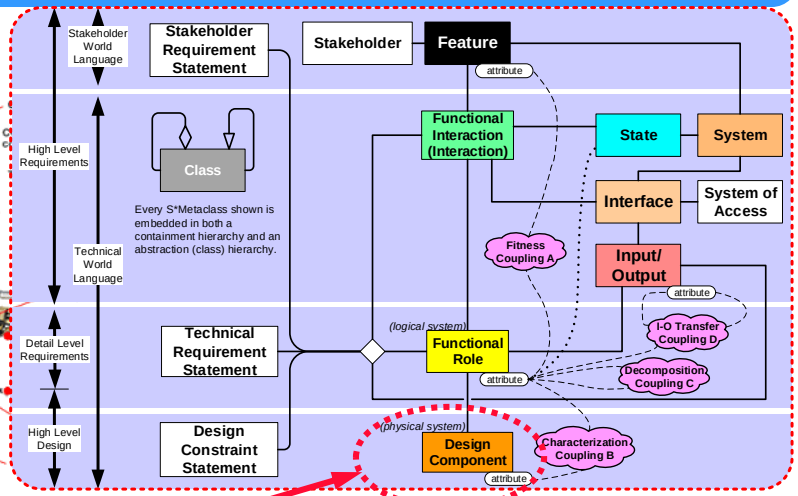
Architecture 1:



Architecture 2:



Different architectures



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

Different attribute values within same architecture

Paper Filter Media

Synthetic Filter Media

Stainless Steel Filter Media

Architecture Loop (few times)

Populating Components & Relationships

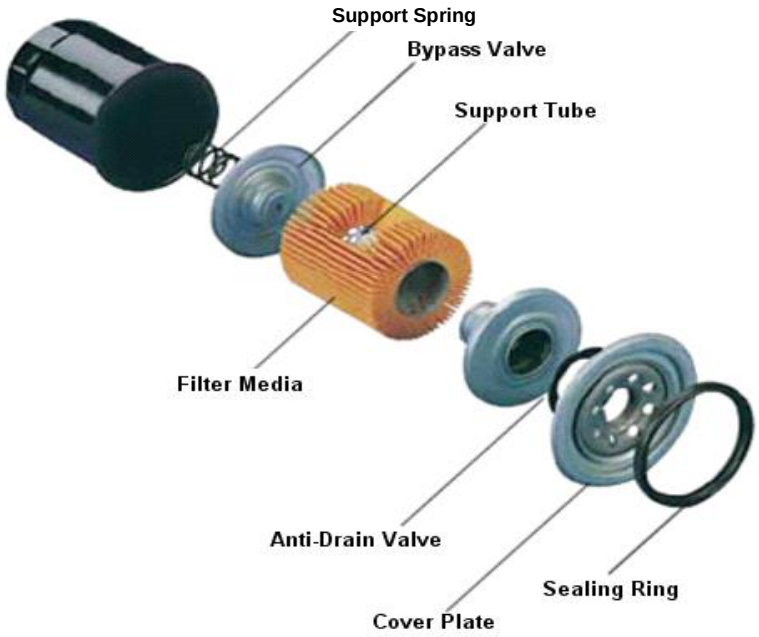
Physical Architecture Model

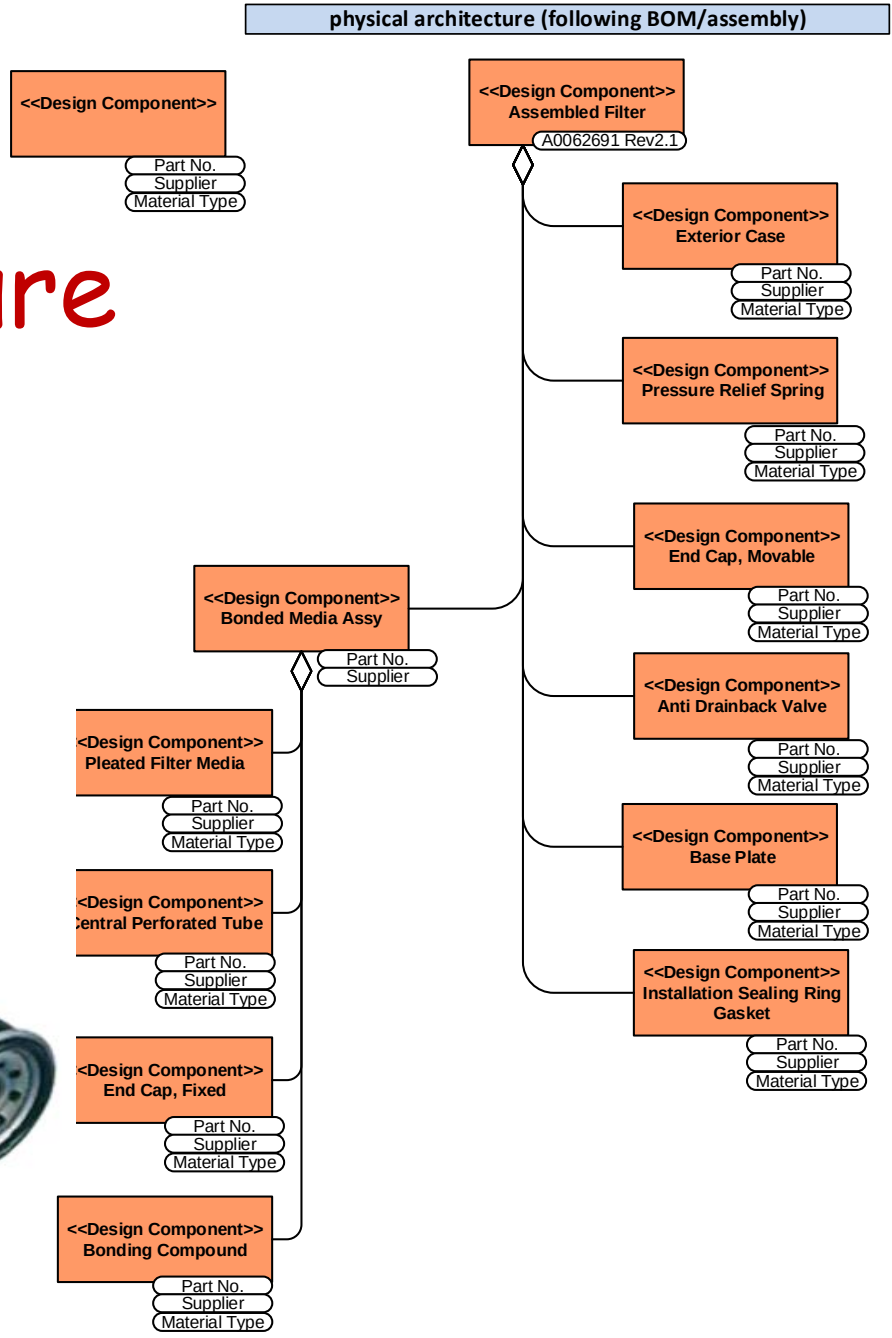
Attribute Tuning Loop (many times)

Setting / Adjusting Attribute Values

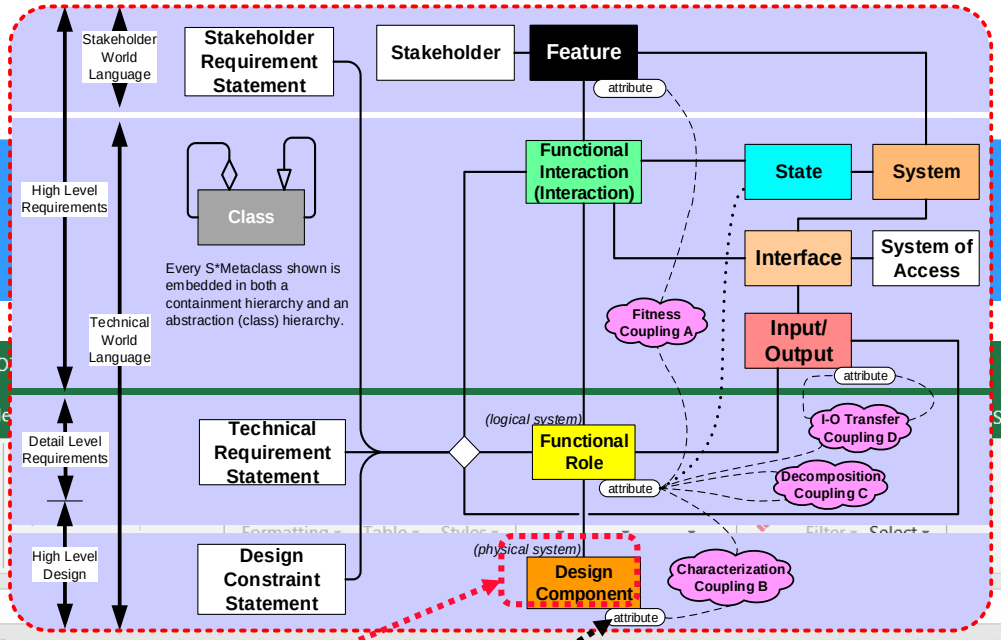
(See Attribute Coupling Model)

Physical Architecture





Physical Architecture



Baseline Workbook 7.0.10 O

File Home Insert Page Layout Formulas Data Review View Developer He Share

Paste Clipboard Arial 10 Font Wrap Text Merge & Center Alignment

F8

	A Container System	B Superclass System	C Physical System Name (Physical Component)	E Configuration Rule	F System Definition	G Attributes	H Domain Diagram	I Physical Arch Diagram	J System Status	L No Roles Allocated	Q No Failure Modes
1											
2	Assembled Filter		Exterior Case			Part No., Material, , 0					
3	Assembled Filter		Central Perforated Tube			Part No., Material, , 0					
4	Assembled Filter		Pleated Filter Media			Part No., Material, Surface Area, 0					
5	Assembled Filter		Base Plate			Part No., Material, , 0					
6	Assembled Filter		Installation Sealing Ring Gasket			Part No., Material, , 0					
7	Assembled Filter		Anti Drainback Valve			Part No., , , 0					
8	Assembled Filter		Support Spring								
9	Assembled Filter		End Cap, Lower								
10	Assembled Filter		Lower Bounding Compound								
11	Assembled Filter		Upper End Cap, With Valve								
12	Assembled Filter		Bonded Media Assy								
13			Assembled Filter								
14	Assembled Filter		Upper Bonding Component								
15											

PA Diagram | Physical Systems | Phys Comp Atts | Role-Design | References | Feature Attrib ...

80%

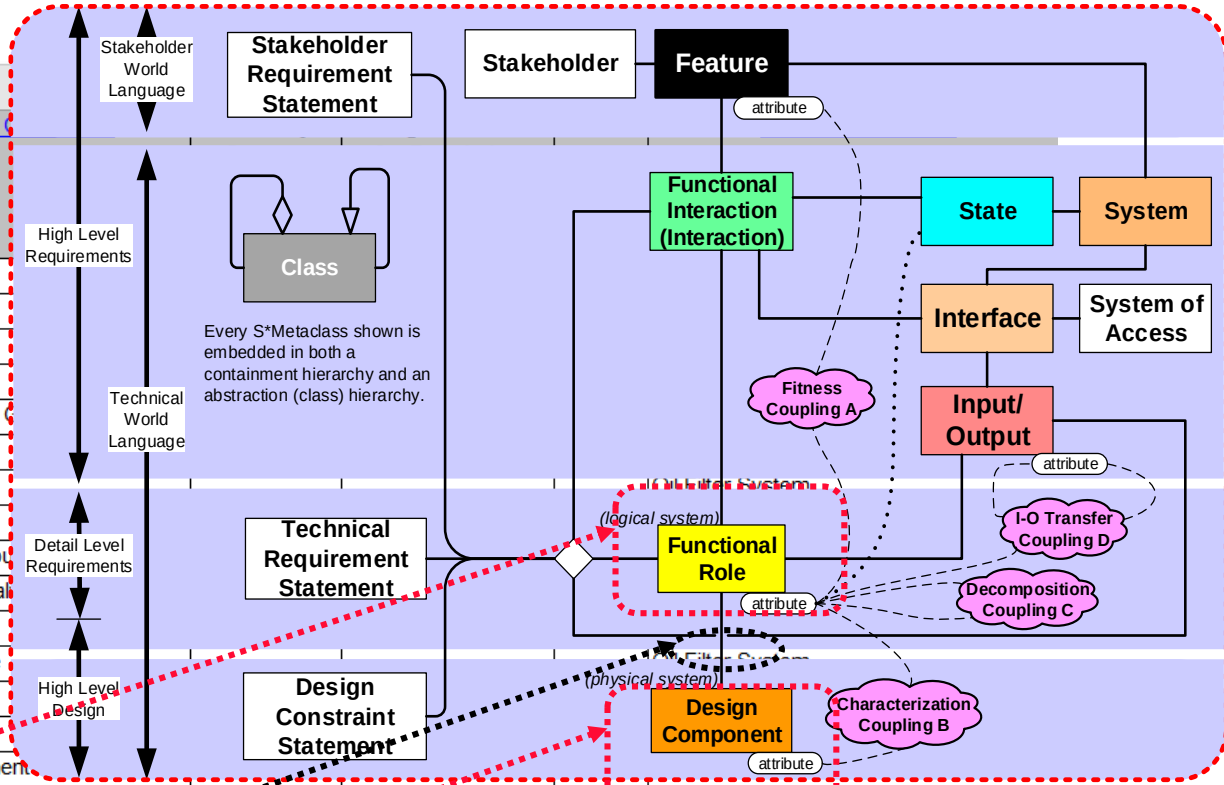
5:18 PM
3/28/2019

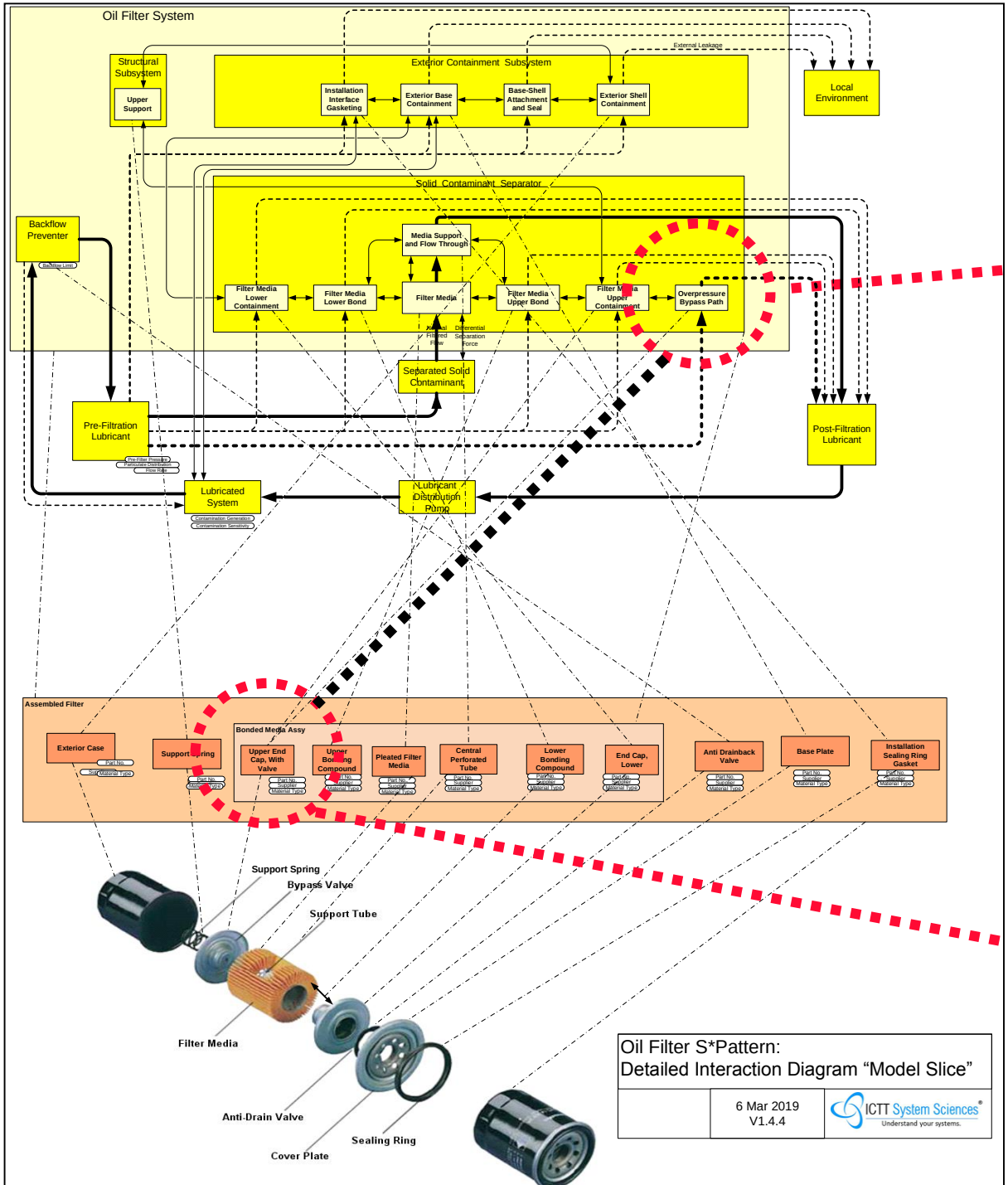
Allocations of roles to physical architecture

	B	D
1	Logical Component Role	Physical Design
2	Exterior Shell Containment	Exterior Case
3	Solid Contaminant Separator	Bonded Media Assy
4	Filter Media	Pleated Filter Media
5	Base-Shell Attachment and Seal	Base Plate
6	Installation Interface Gasketing	Installation Sealing Ring
7	Backflow Preventer	Anti Drainback Valve
8	Exterior Containment Subsystem	Assembled Filter
9	Filter Media Lower Containment	End Cap, Lower
10	Filter Media Lower Bond	Lower Bounding Compou
11	Overpressure Bypass Path	Upper End Cap, With Val
12		
13	Media Support and Flow Through	Central Perforated Tube
14	Oil Filter System	Assembled Filter
15	Thermal Energy Distributor	
16	Filter Media Upper Bond	Upper Bonding Component
17	Filter Media Upper Containment	Upper End Cap, With Valve
18	Upper Support	Support Spring
19	Exterior Base Containment	Base Plate
20	Exterior Shell Containment	Exterior Case
21		
22		
23		

17		Oil Filter System
18		Oil Filter System
19		Oil Filter System
20		Oil Filter System

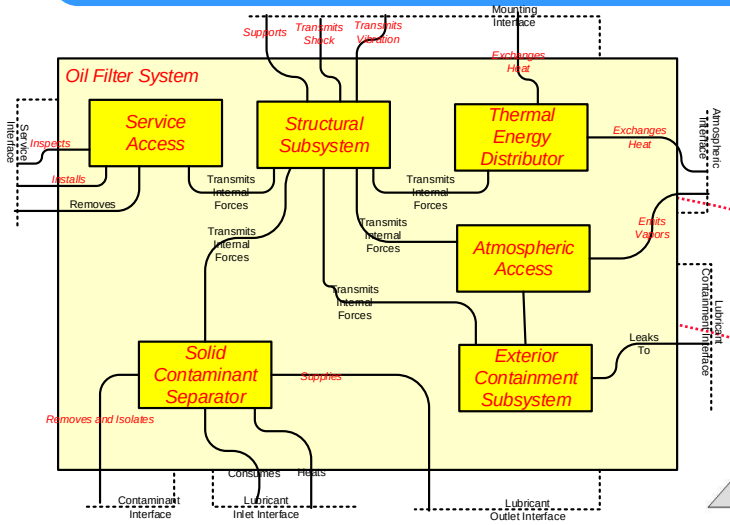
Physical Systems | Phys Comp Atts | Role-Design | References | Feature Attribute Couplings

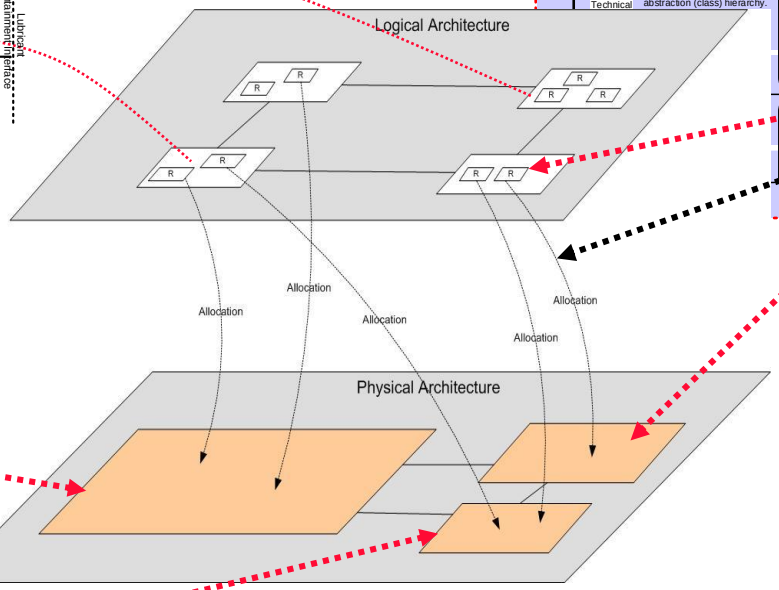


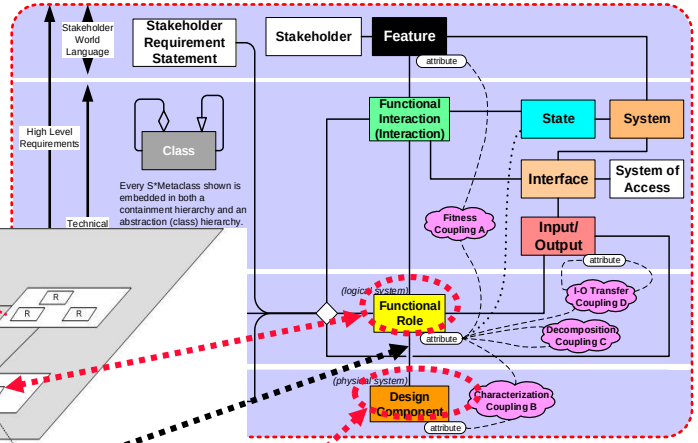

Oil Filter System
Structural Subsystem
Upper Support
Exterior Containment Subsystem
External Leakage
Installation Interface Gasketing
Exterior Base Containment
Base-Shell Attachment and Seal
Exterior Shell Containment
Local Environment
Solid Contaminant Separator
Backflow Preventer
Media Support and Flow Through
Filter Media Lower Containment
Filter Media Lower Bond
Filter Media
Filter Media Upper Bond
Filter Media Upper Containment
Overpressure Bypass Path
Filtered Flow
Differential Separation Force
Separated Solid Contaminant
Pre-Filtration Lubricant
Post-Filtration Lubricant
Lubricated System
Lubricant Distribution Pump
Assembled Filter
Exterior Case
Support Spring
Bonded Media Assy
Upper End Cap, With Valve
Upper Bonding Compound
Pleated Filter Media
Central Perforated Tube
Lower Bonding Compound
End Cap, Lower
Anti Drainback Valve
Base Plate
Installation Sealing Ring Gasket
Support Spring
Bypass Valve
Support Tube
Filter Media
Anti-Drain Valve
Sealing Ring
Cover Plate
Overpressure Bypass Path
Bonded Media Assy
Upper End Cap, With Valve
Part No.
Supplier
Material Type
Oil Filter S*Pattern:
Detailed Interaction Diagram “Model Slice”
6 Mar 2019
V1.4.4
ICTT System Sciences
Understand your systems.

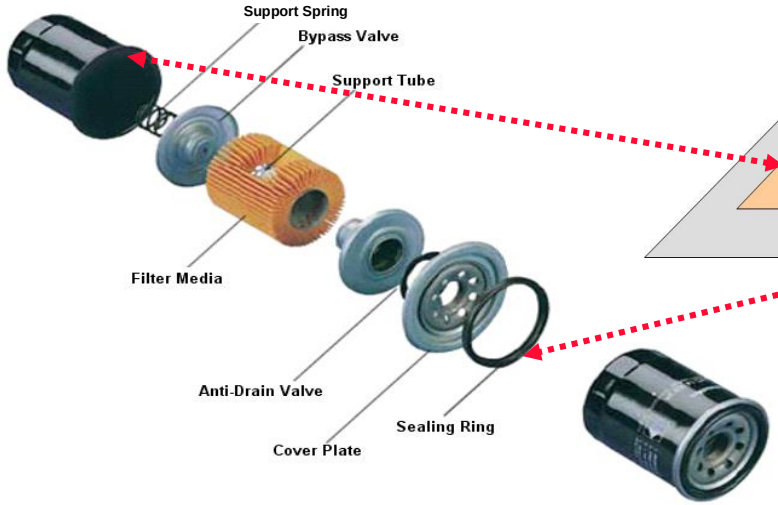
Logical roles are subsets of system behavior that formally model subsystems even though they have not been allocated yet to physical designs.

Allocating Logical Architecture to Physical Architecture



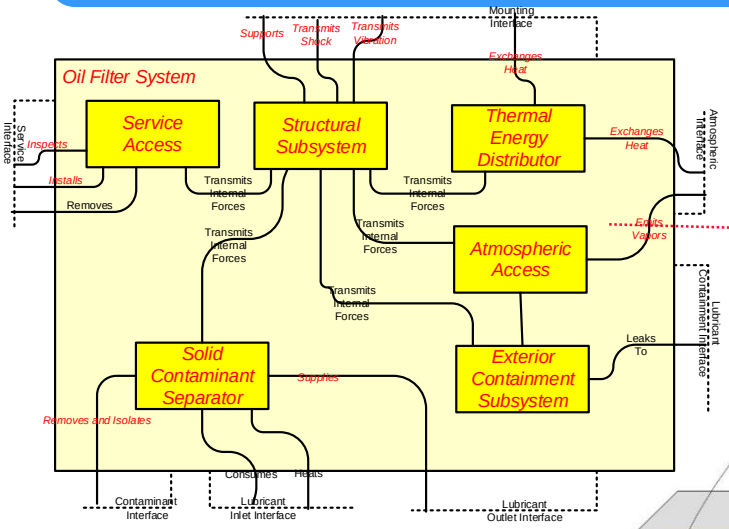


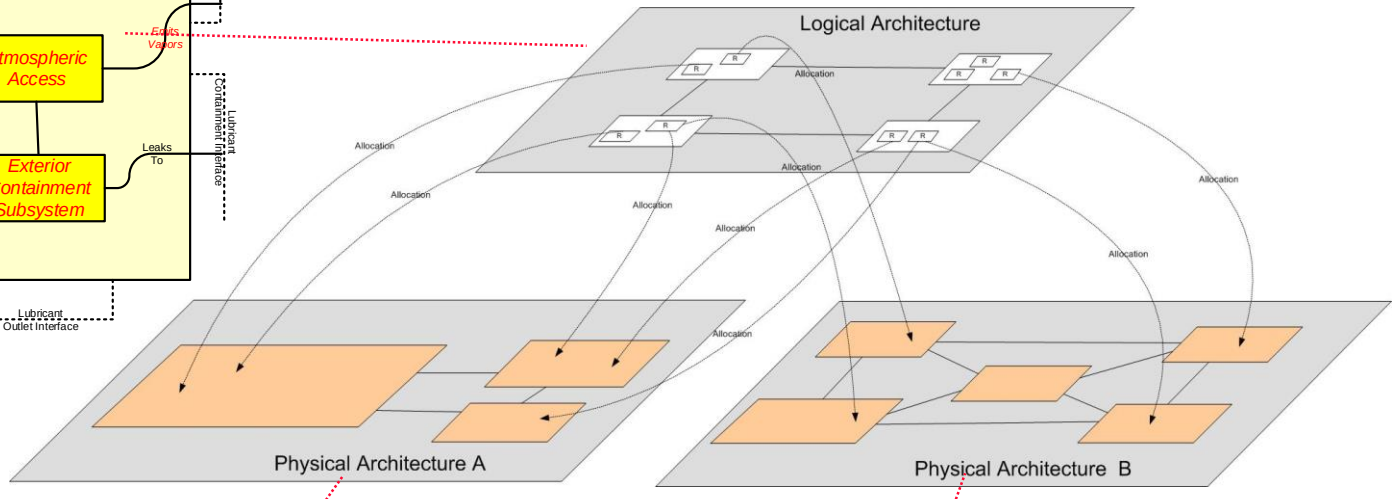


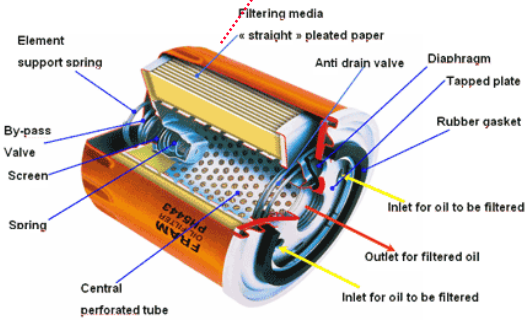


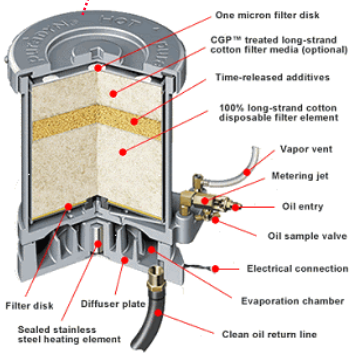
Directly addressing a key SE challenge, multiple alternate physical architectures are typically supported by a single Logical Architecture! This provides a powerful means for managing across Technologies & Configurations, and enhances Platform Management.

Alternate Architecture, Technologies, Configurations



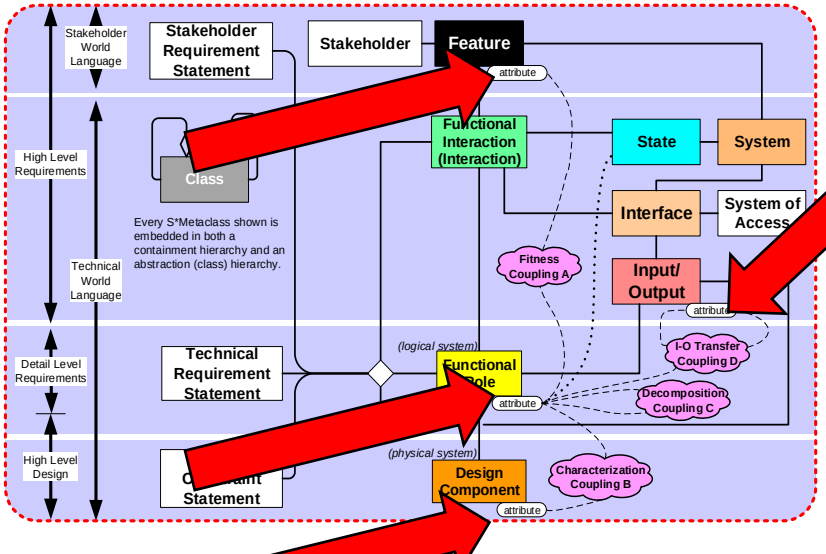






Attribute Couplings

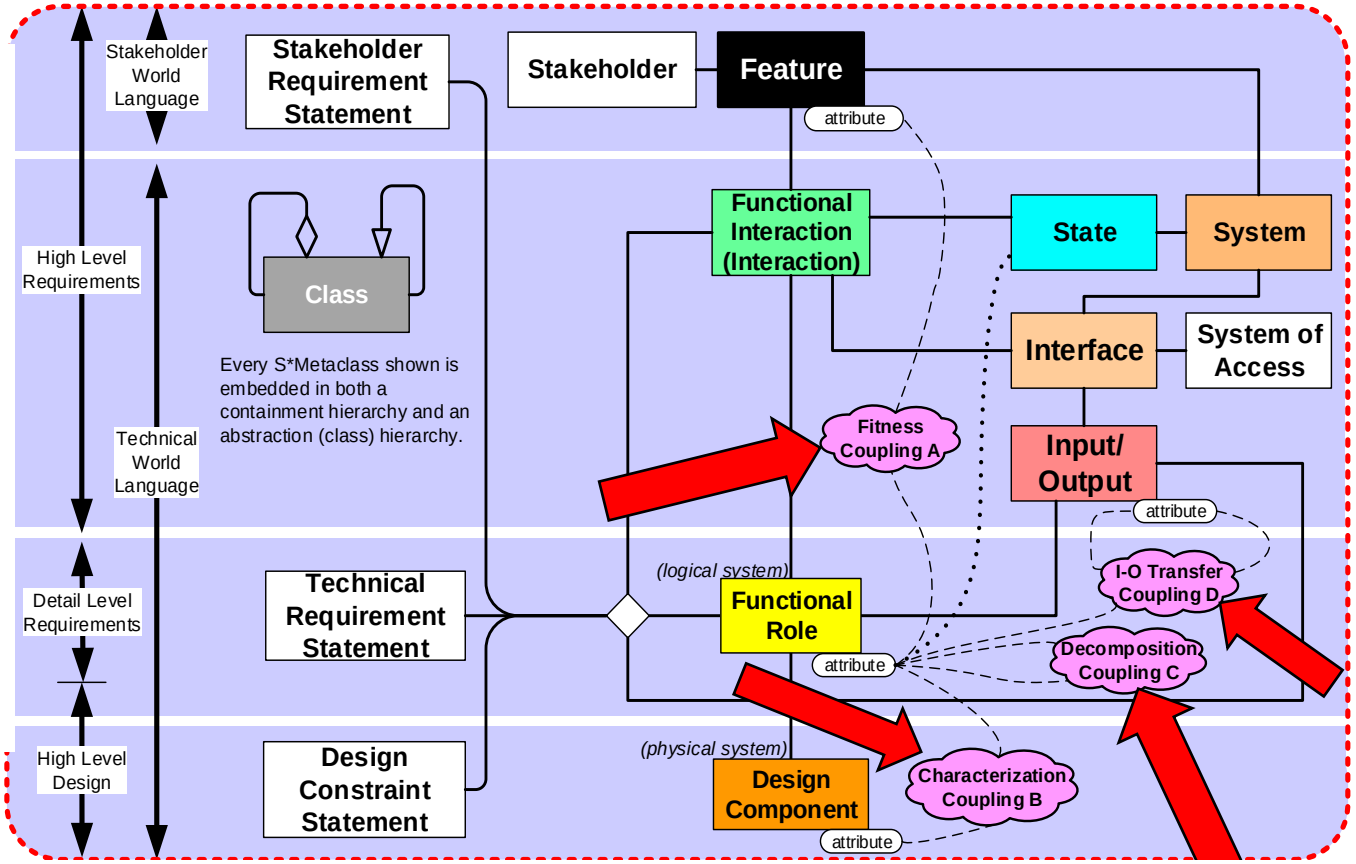
- Attribute Couplings express parametric relationships between attributes:
  - Kinetic Energy = Mass x (Velocity)^2
  - Market Share = TableLookup14(Functional Performance, Reliability, Weight)
  - Generated Power = Input Power x Efficiency
  - Reliability = F_{RB}(Bonding Time, Bonding Temperature, Bonding Pressure)
- Couples the attributes of:
  - Stakeholder Features,
  - Functional Roles
  - Design Components
  - Input-Outputs



Attribute Couplings

Four types of Attribute Couplings:

A. Fitness Coupling
B. Characterization Coupling
C. Decomposition Coupling
D. IO Transfer Coupling



- Natural places for simulations, other computational models

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

Microsoft Excel - Oil Filter Pattern V1.1.3.xls

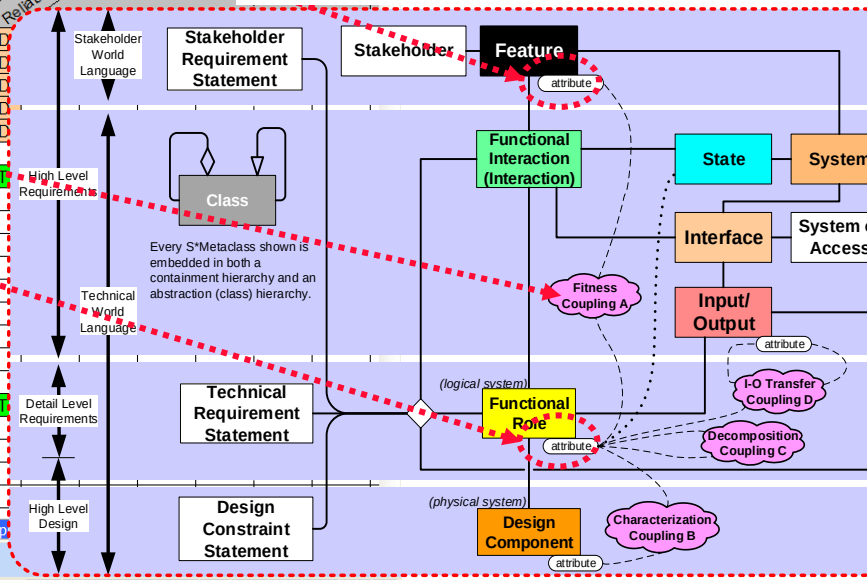
Requirements Coupling Matrix A

Feature / Attribute

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 Rating	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
End Seal Bonder / Bonding Pressure				BND							BND
End Seal Bonder / Bonding Time				BND							BND
End Seal Bonder / Bonding Temperature				BND							BND
End Seal Bonder / Bond Tensile Strength				BND							BND
End Seal / In Service Seal Failure Rate				BND							BND
Lubricant / Lubricant Type		FLT						FLT			
Lubricant / Lubricant Service Pressure Range		FLT									FLT
Lubricant / Lubricant Flow Rate			FLT								
Filter Media / Filter Efficiency at 80 Microns	FLT	FLT			FLT						
Filter Media / Filter Efficiency at 60 Microns	FLT	FLT			FLT						
Filter Media / Filter Efficiency at 40 Microns	FLT	FLT			FLT						
Filter Media / Filter Efficiency at 30 Microns	FLT	FLT			FLT						
Filter Media / Filter Efficiency at 20 Microns	FLT	FLT			FLT						
Filter Media / Filter Efficiency at 15 Microns	FLT	FLT			FLT						
Filter Media / Filter Efficiency at 10 Microns	FLT	FLT			FLT						
Filter Media / Filter Impurity Storage Capacity											
Filter Media / Minimum Failure Pressure											FLT
Filter Media / Surface Area						FLT					
Filter Media / Beta Ratio											
Contaminant Source / Contaminant Injection Rate	FLT				FLT			FLT	FLT		
End Seal Bonder / Manufacturing Process Cost										BND	

Requirements Coupling Matrix A | References | PA Diagram | Physical Systems | Phys Comp Atts | Role-Design | Design Coup

Ready Calculate



- 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

Microsoft Excel - Oil Filter Pattern V1.1.4.xls

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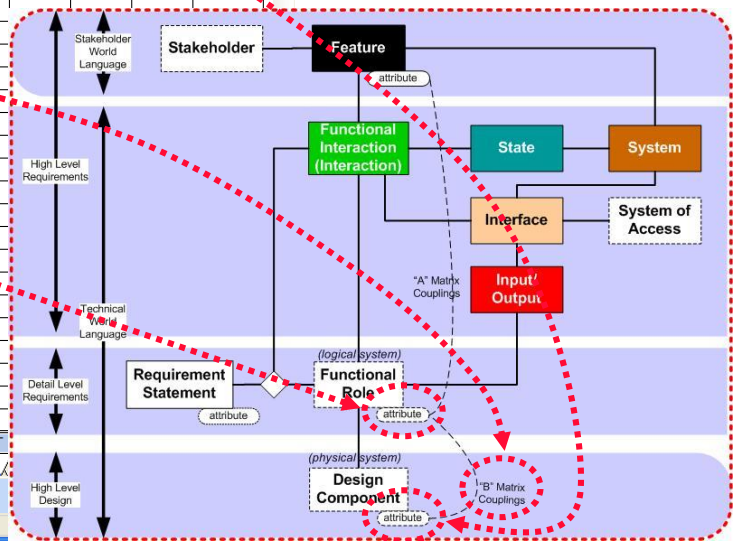
J24 MCST

	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 /	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		

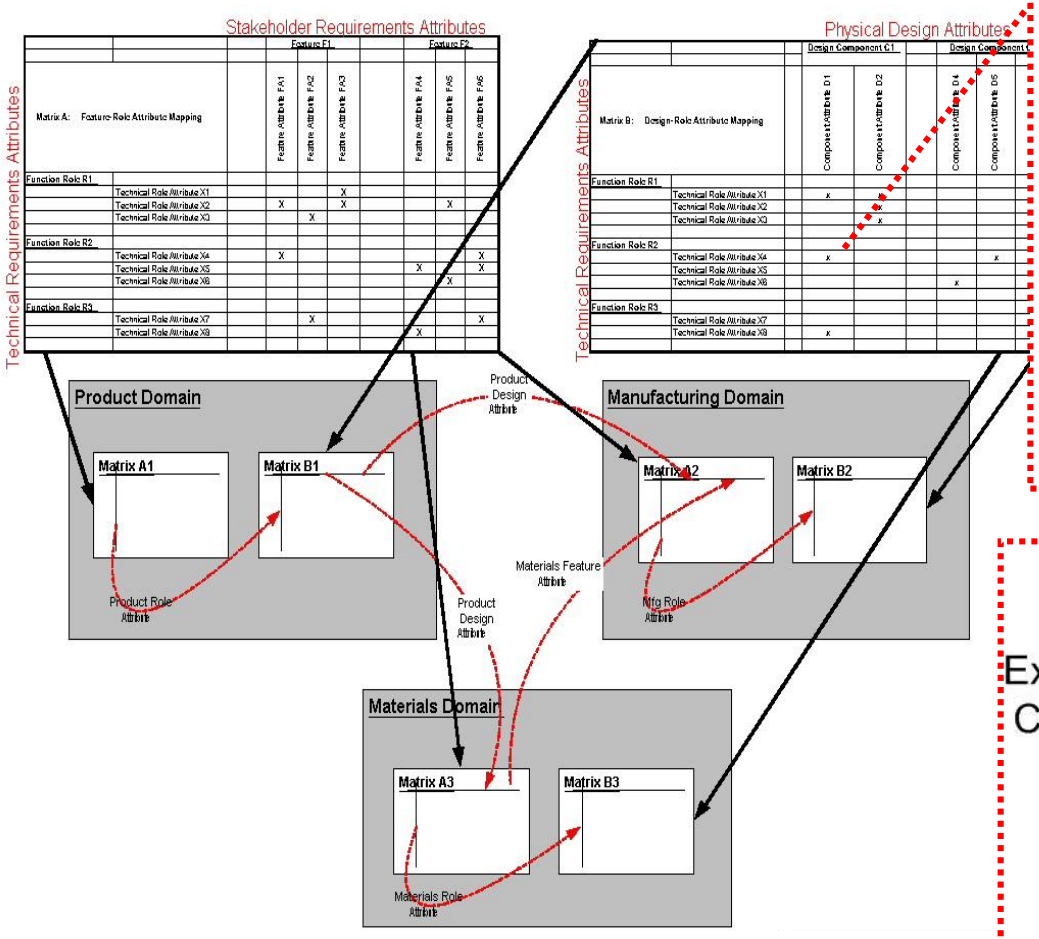
Requirements Coupling Matrix A | References | PA Diagram | Physical Systems | Phys Comp Atts | Role-Design | Design Coupling Matrix B

Ready Calculate

- 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.

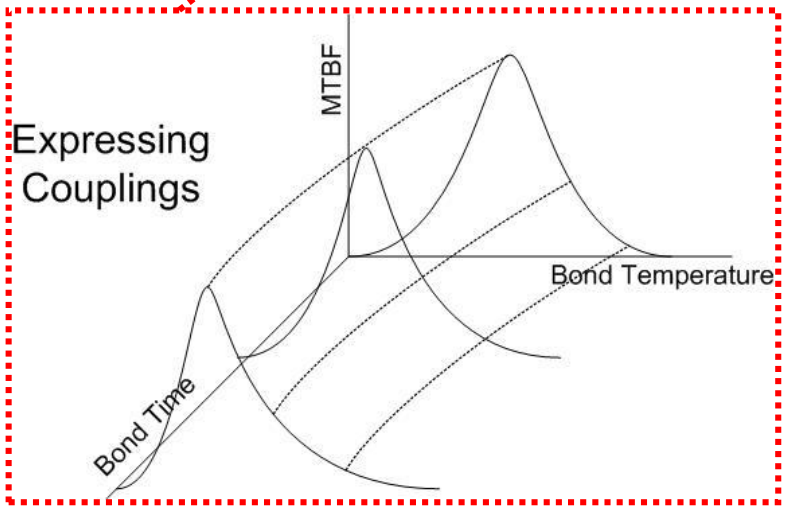


Attribute couplings cross domains

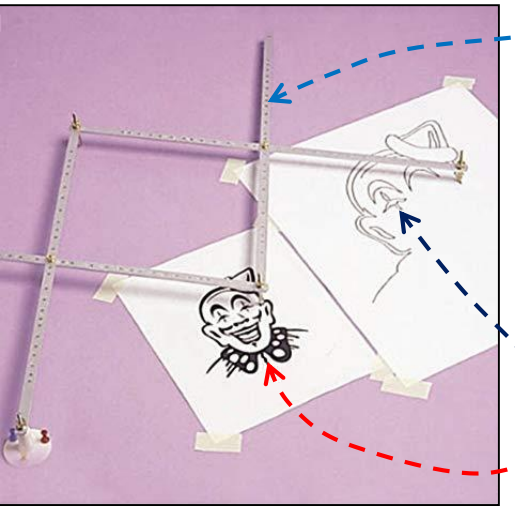


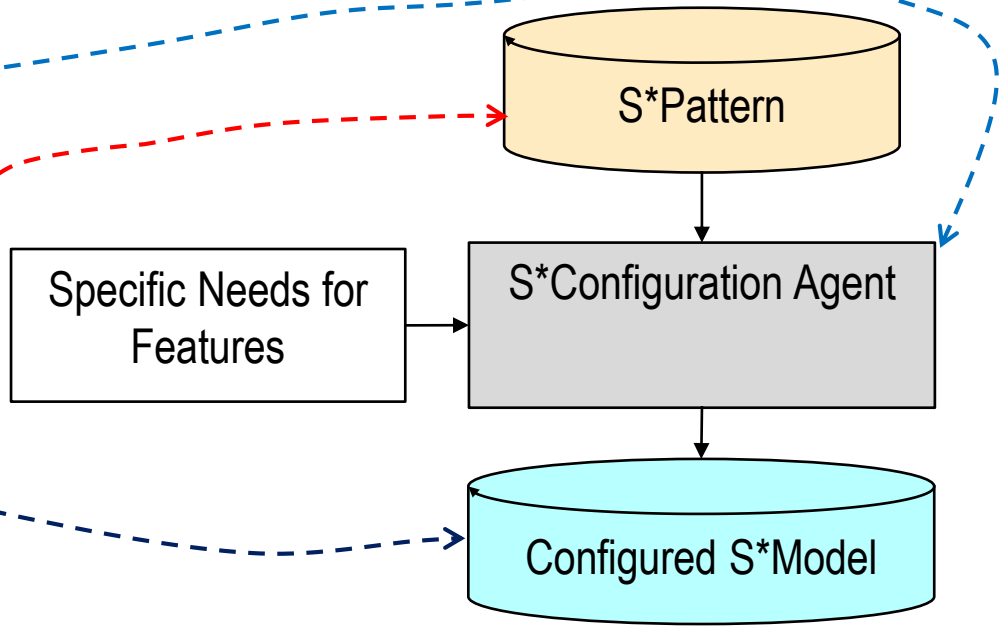
The Coupling Model is a unifying framework integrating all forms of coupling:

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

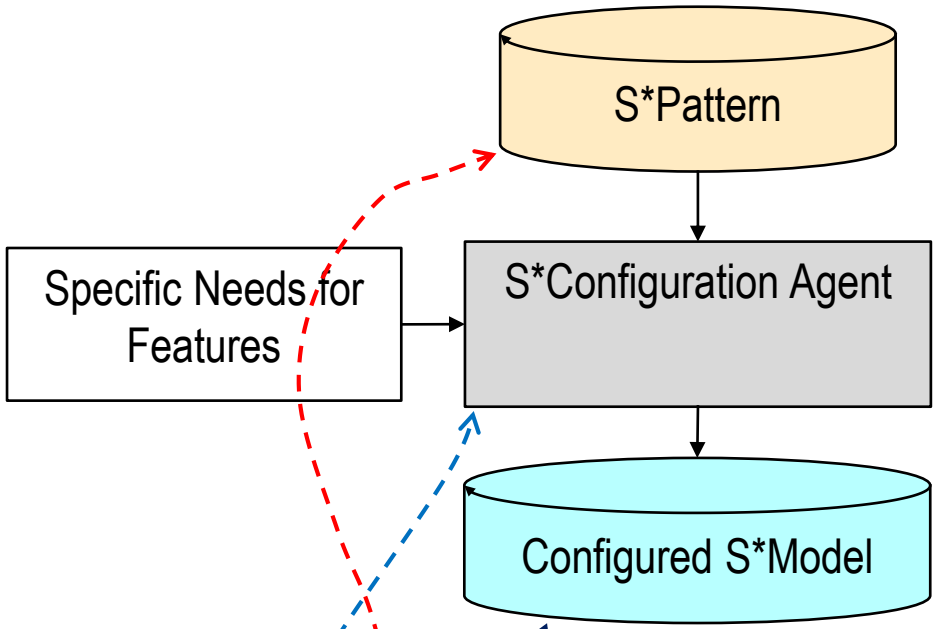


Generating Configurations from Patterns





Generating Configurations from Patterns



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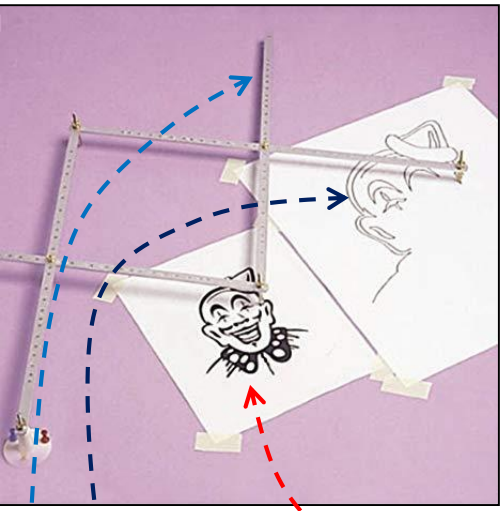
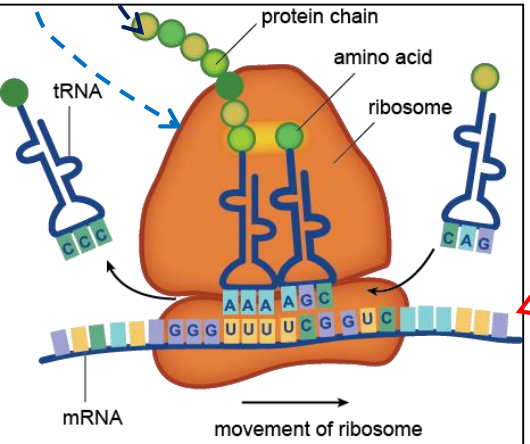
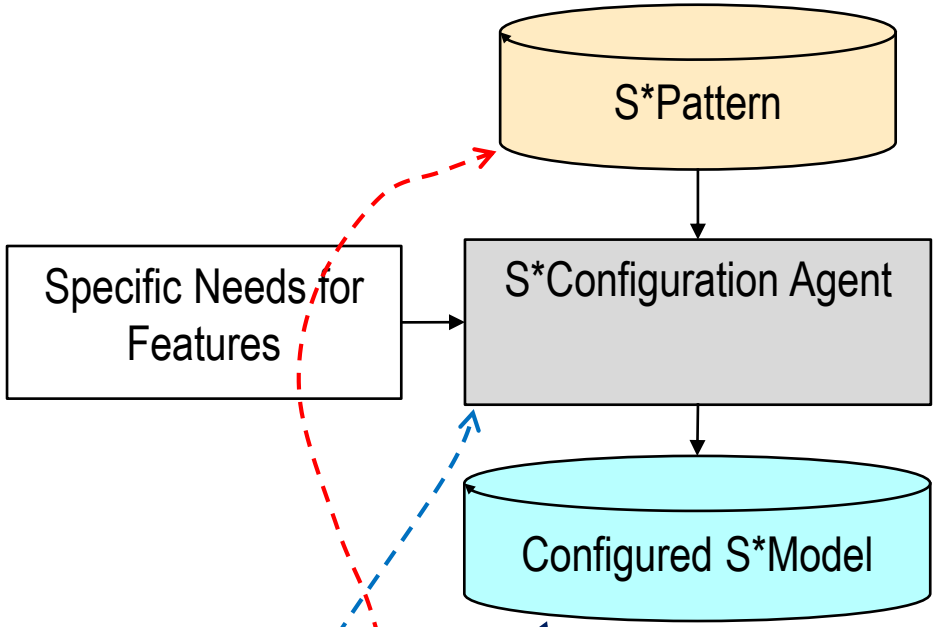
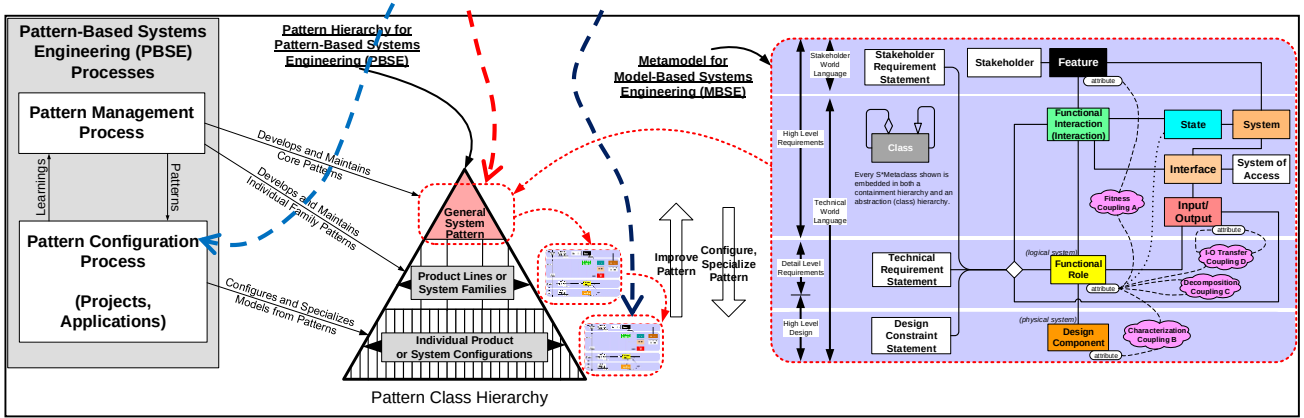
Generating Configurations from Patterns

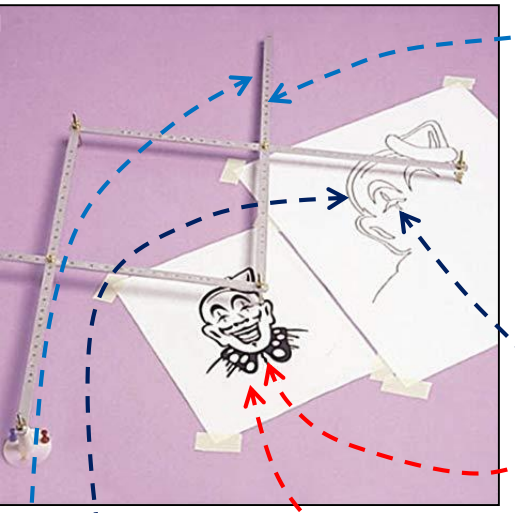








Generating Configurations from Patterns

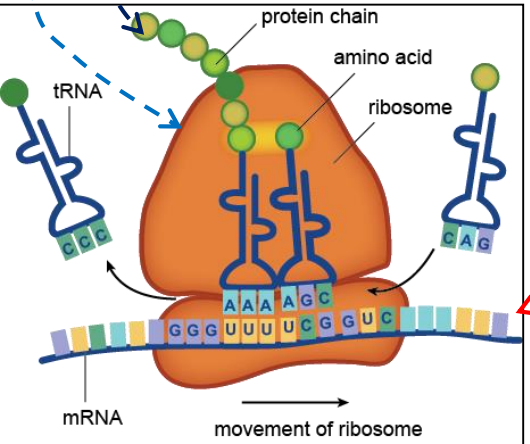


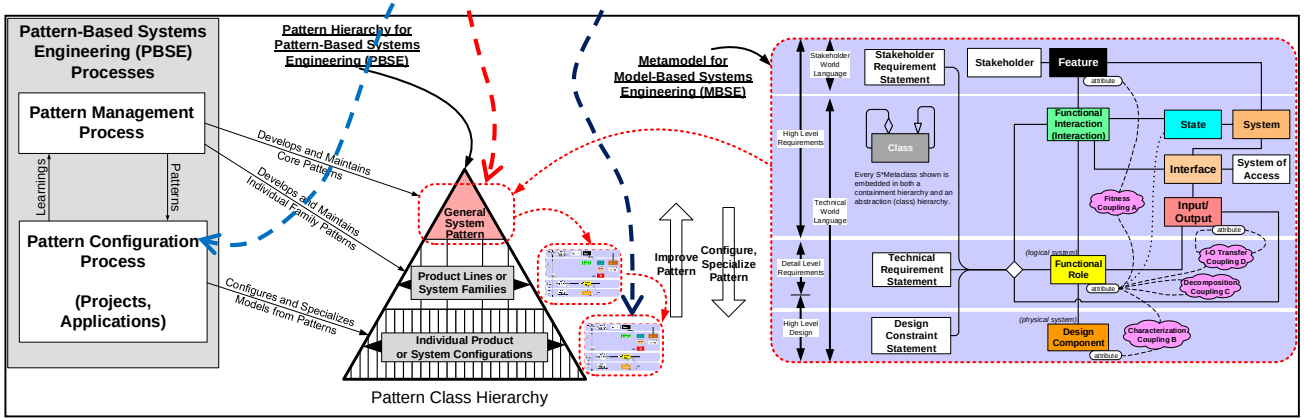
S*Pattern

Specific Needs for Features

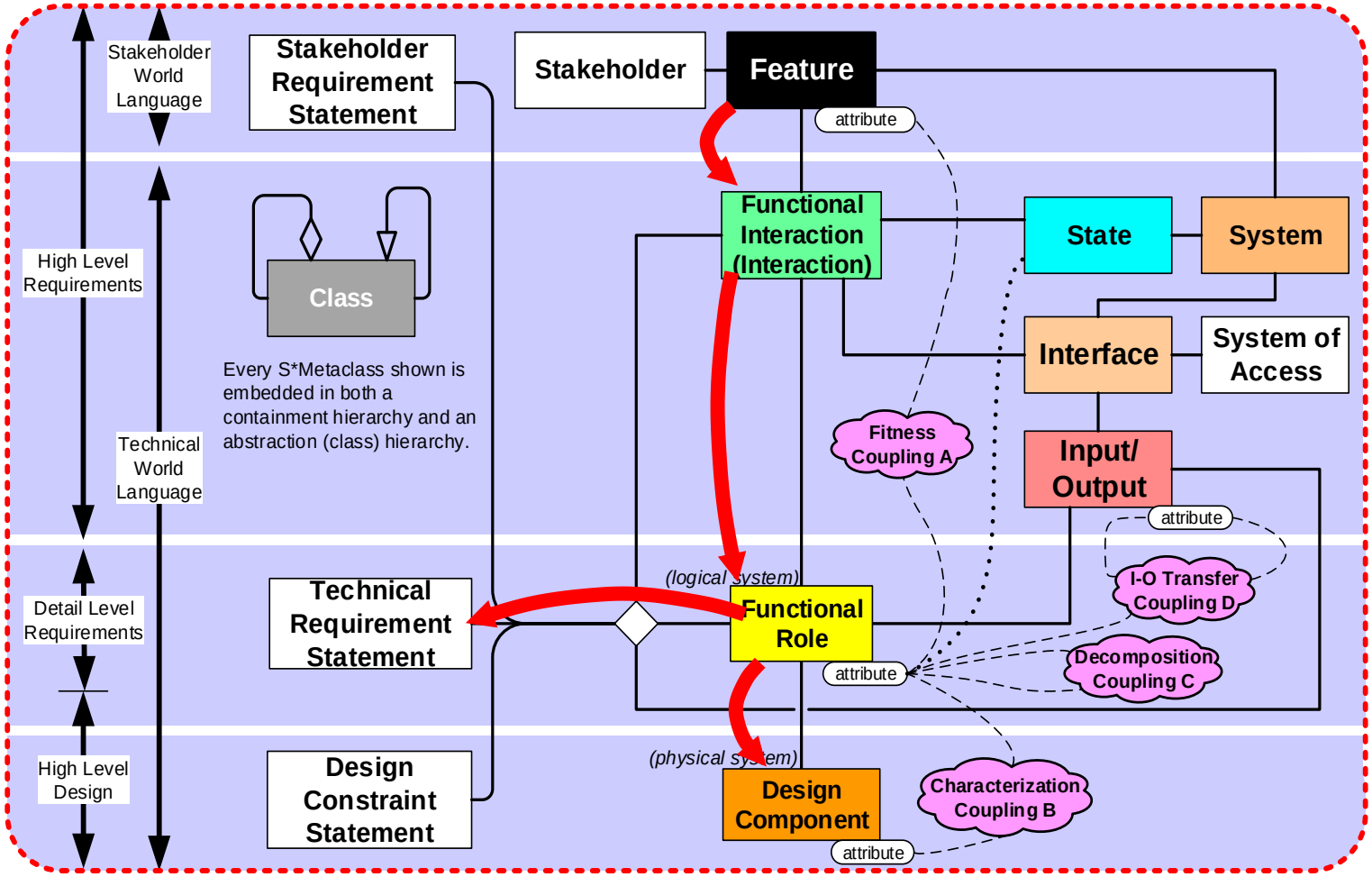
S*Configuration Agent

Configured S*Model





Pattern Configuration Pathway



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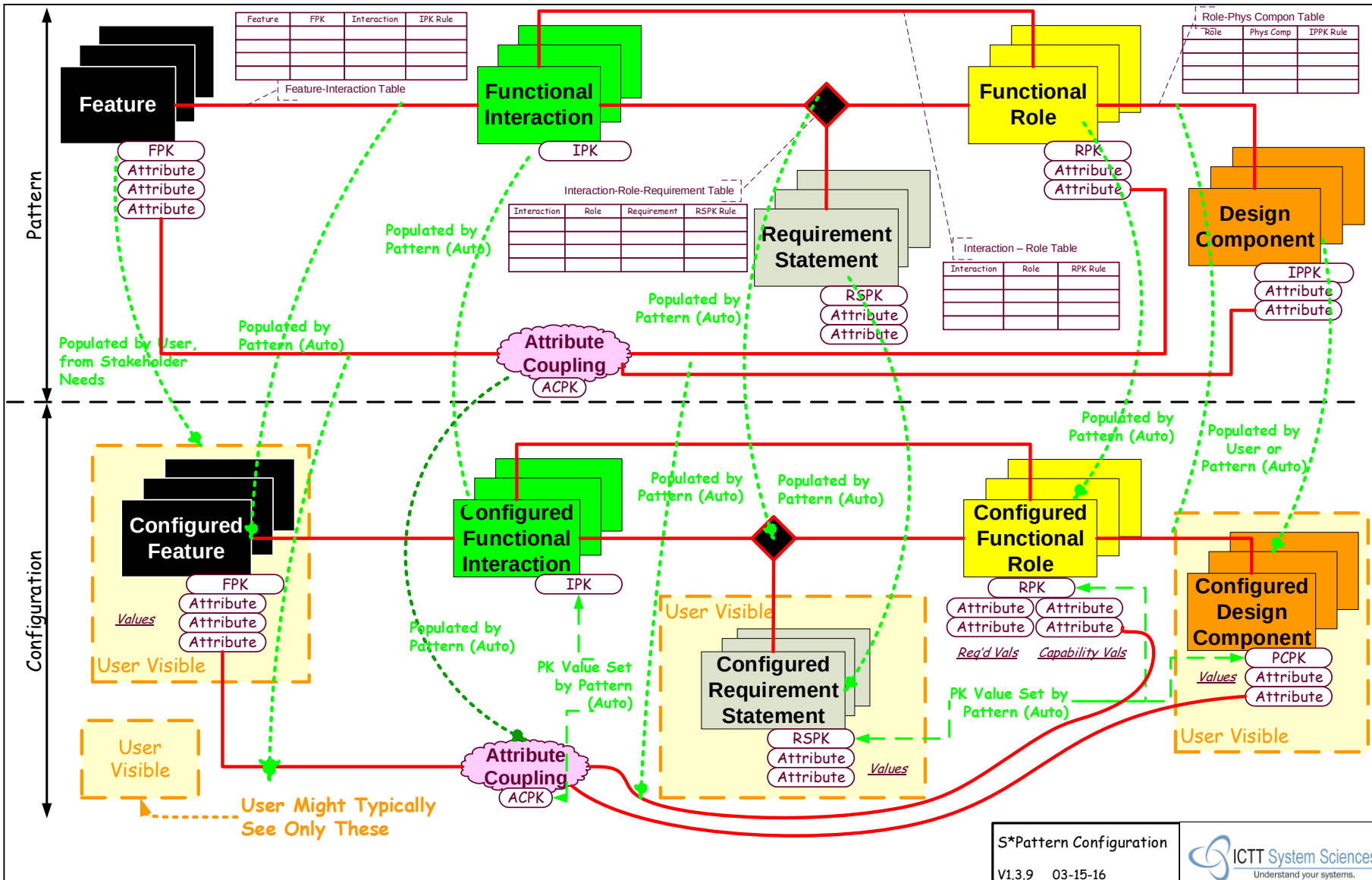
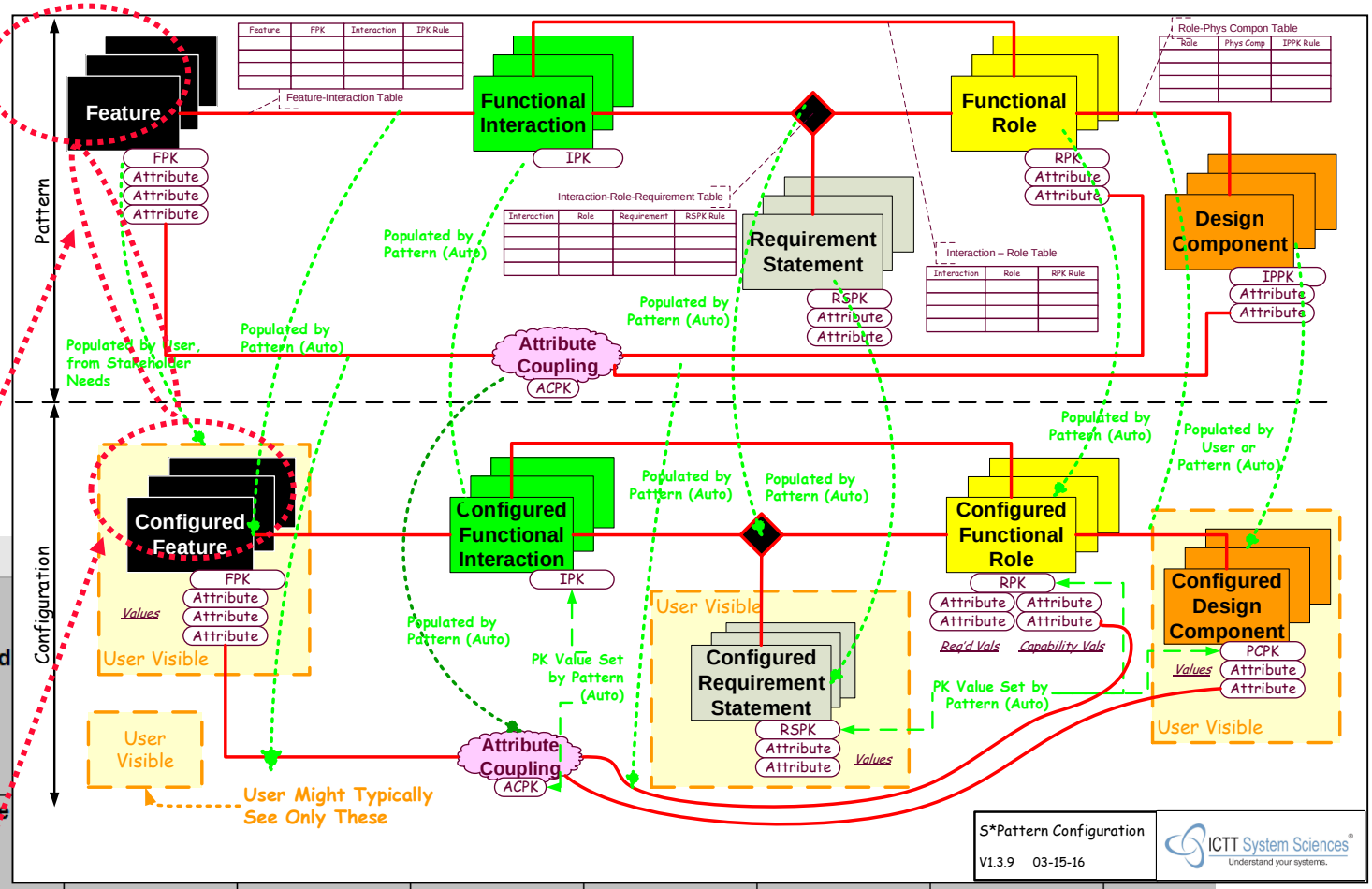
Pattern Configuration Pathway



1. Populate Features from Pattern

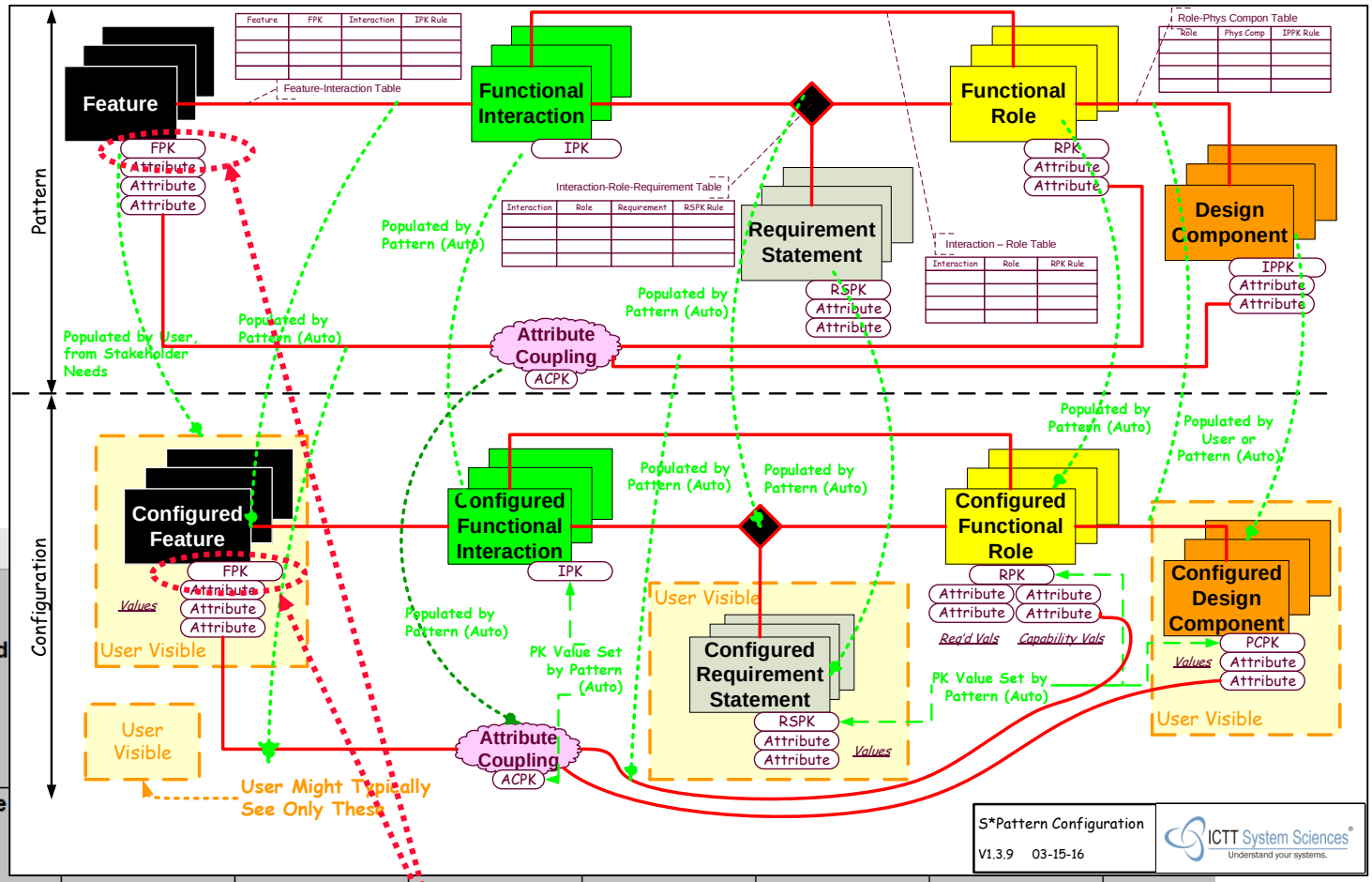


	E	H							
4		No. Populated Features: 04							
5	Populate? (YES/NO)	Feature Name	(PK) Attribute Name						
6									
7	YES	Filter Application	Service Application	Commercial Automotive	Cold Environment				
8	NO	Mechanical Compatiblity Feature	--						
9	NO	Cost of Operation Feature	--						
10	YES	Reliability Feature	--						
11	NO	East of Installation Feature	--						
	NO	Additive Feature	Additive Type						

Cold Environment
Commercial Automo
Consumer Automoti
Fixed Base Engine Sy
Harsh Environment
High Thermal Enviro

Stkhdr Config | 1. Feature Population | 2. Feat Att Values | Backup Feat Att Values | Interact ...

2. Set Feature Primary Key Attribute Values

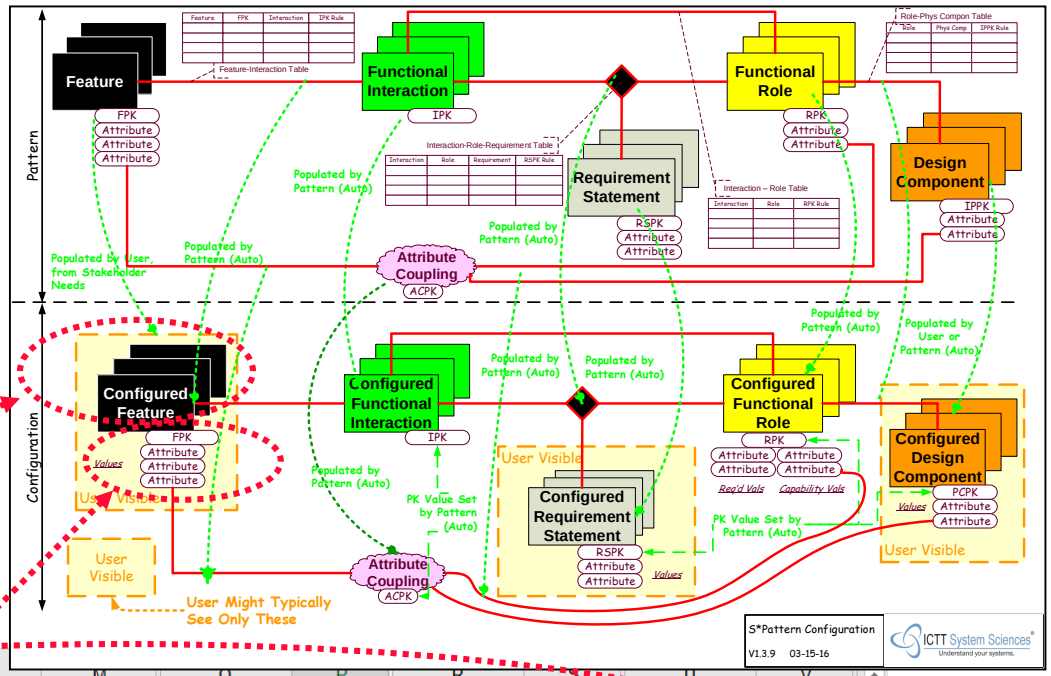


	E	H							
4		No. Populated Features: 04							
5	Populate? (YES/NO)	Feature Name	(PK) Attribute Name						
6									
7	YES	Filter Application	Service Application	Commercial Automotive	Cold Environment				
8	NO	Mechanical Compatiblity Feature	--						
9	NO	Cost of Operation Feature	--						
10	YES	Reliability Feature	--						
11	NO	East of Installation Feature	--						
	NO	Additive Feature	Additive Type						

Cold Environment
Commercial Automo
Consumer Automotiv
Fixed Base Engine Sy
Harsh Environment
High Thermal Enviro

Stkhdr Config | 1. Feature Population | 2. Feat Att Values | Backup Feat Att Values | Interact ...

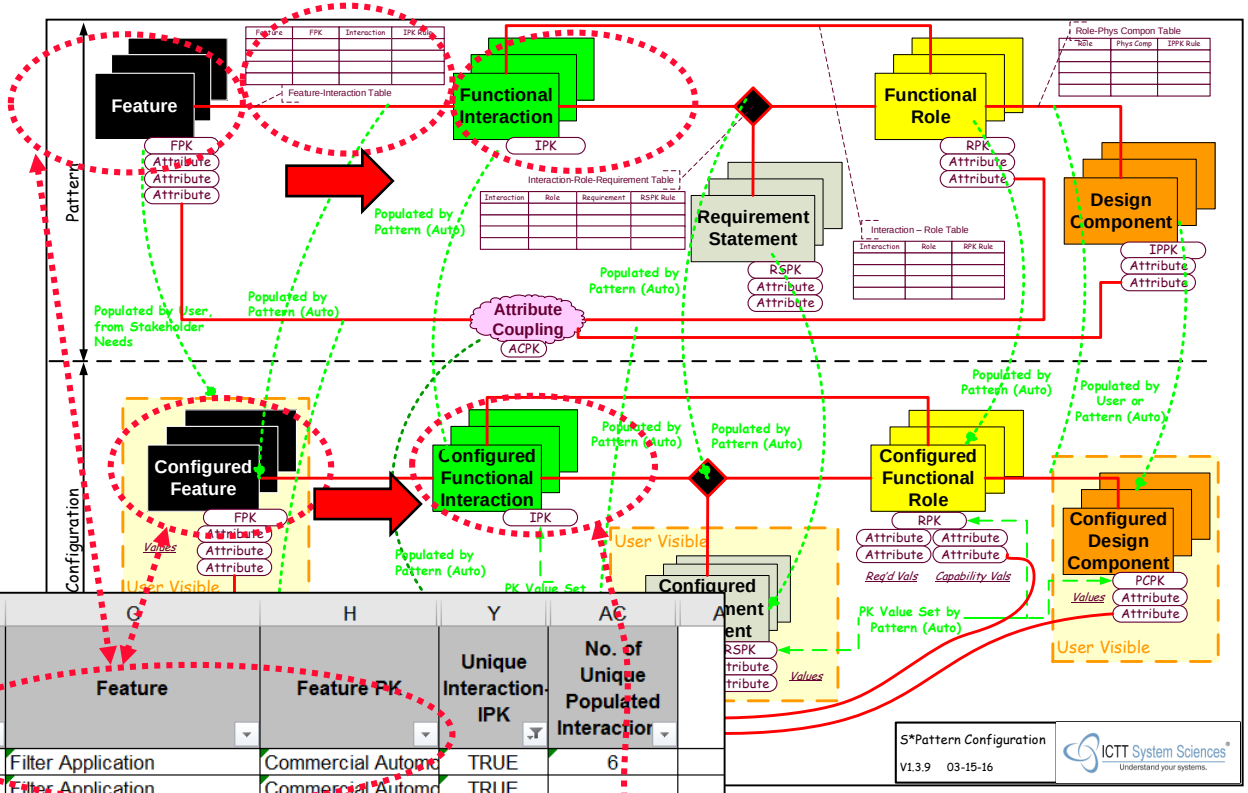
3. Set other Feature Attributes Values



	A	B	C	I	J	L	M	O	P	R	S	U	V
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**
2	Filter Application	Service Application	Commercial Automotive	Service Application	Commercial Automotive	Lubricant Type		Lubricant Flow Rate	6.5	Lubricant Pressure Range		Filter Efficiency Class	
3	Filter Application	Service Application	Cold Environment	Service Application	Cold Environment	Lubricant Type		Lubricant Flow Rate		Lubricant Pressure Range		Filter Efficiency Class	
4	Reliability Feature	--		Reliability									
5	Environmentally Friendly Feature	Environmental Issue	Oil Leakage	Environmental Issue	Oil Leakage								
6	Health & Safety	H&S Hazard Type	Pressurized Equipment	H&S Hazard Type	Pressurized Equipment								
	Health & Safety	H&S Hazard Type	Toxic or Reactive Materials	H&S Hazard Type	Toxic or Reactive Materials								

1. Feature Population | 2. Feat Att Values | Backup Feat Att Values | Interaction Population

4. Agent Populates Interactions from Related Populated Features and Rules



	A	F	G	H	Y	AC
1	Functional Interaction	Interaction PK	Feature	Feature PK	Unique Interaction-IPK	No. of Unique Populated Interactior
2	Filter Lubricant		Filter Application	Commercial Automc	TRUE	6
3	Bypass Overpressure Lubricant		Filter Application	Commercial Automc	TRUE	
4	Prevent Transient Lubricant Backflow		Filter Application	Commercial Automc	TRUE	
9	Contain Lubricant		Environmentally Friendly Feature	Oil Leakage	TRUE	
10	Protect	Injury & Illness Rate	Health & Safety	Pressurized Equipm	TRUE	
11	Protect	Prevent Occupant Injury	Health & Safety	Pressurized Equipm	TRUE	
501						
502						
503						
504						
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508						
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516						
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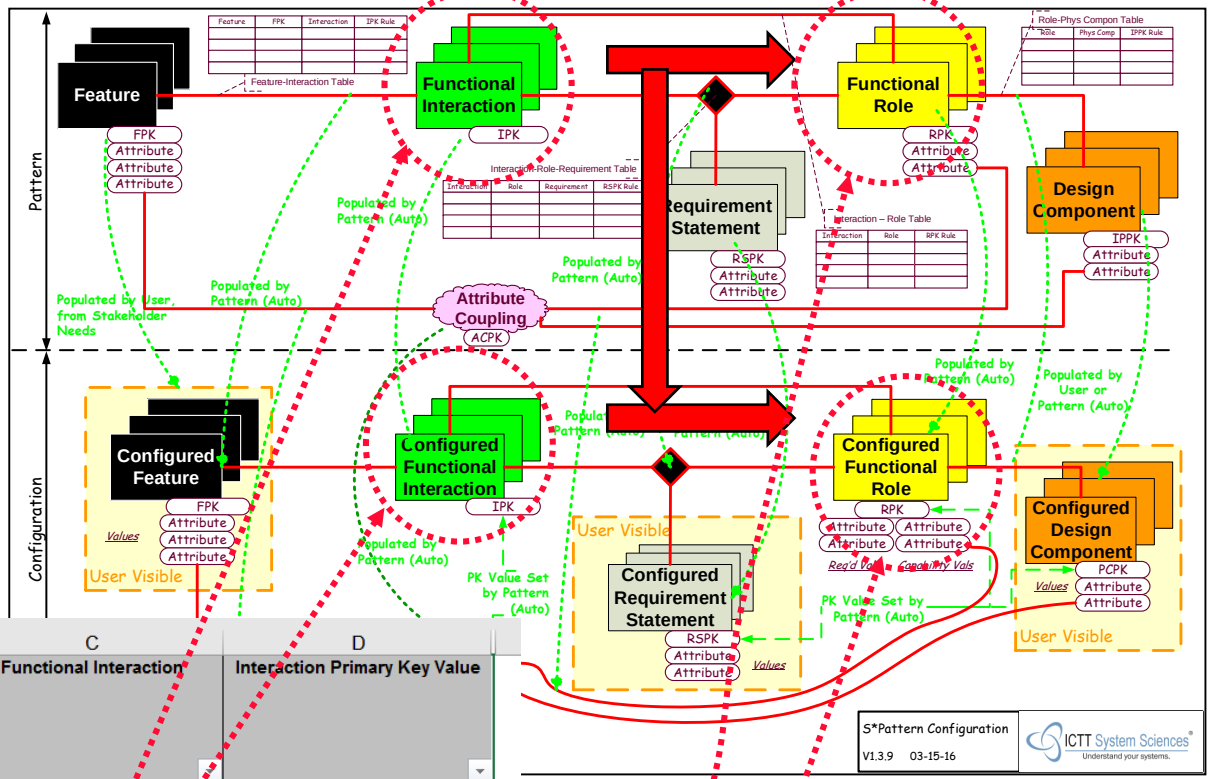
1. Feature Population | 2. Feat Att Values | Backup Feat Att Values | Interaction Population

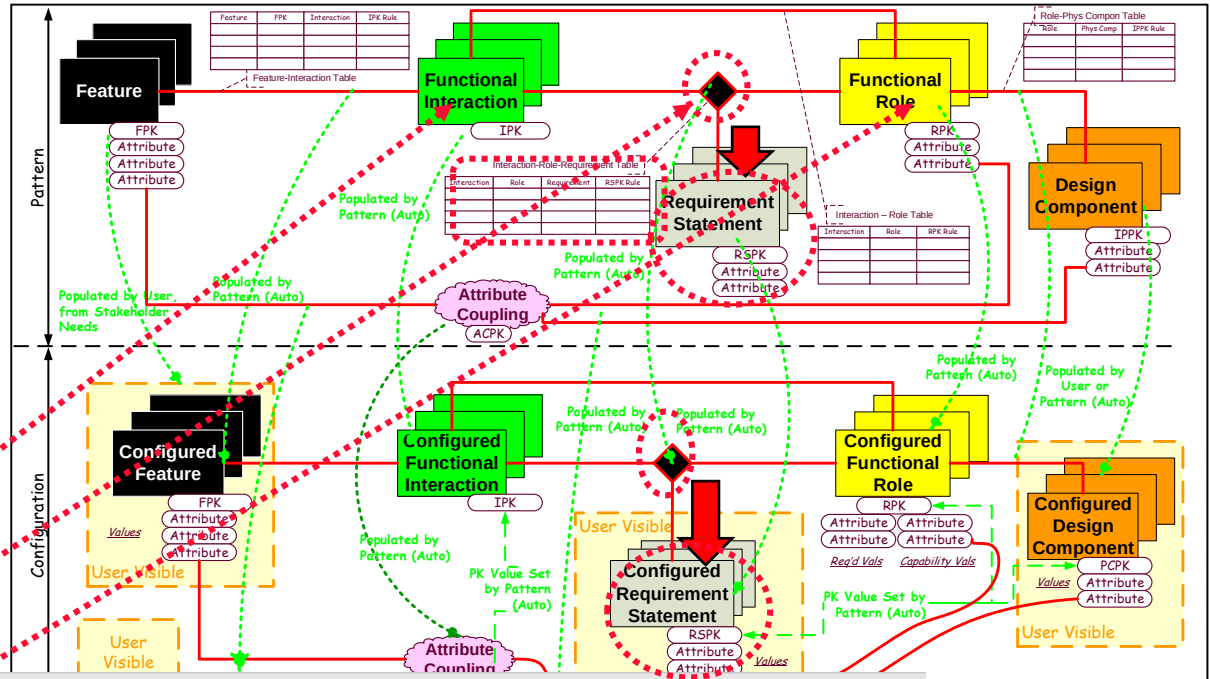
5. Agent Populates Roles from Populated Interactions and Rules



	A	B	C	D
1	Functional Role	Role Primary Key Value	Functional Interaction	Interaction Primary Key Value
2	Oil Filter System		Filter Lubricant	
3	Post-Filtration Lubricant		Filter Lubricant	
4	Pre-Filtration Lubricant		Filter Lubricant	
5	Separated Solid Contaminant		Filter Lubricant	
6	Backflow Preventer		Filter Lubricant	
7	Solid Contaminant Separator		Filter Lubricant	
8	Filter Media		Filter Lubricant	
9	Filter Media Lower Bond		Filter Lubricant	
10	Filter Media Lower Containment		Filter Lubricant	
11	Filter Media Upper Bond		Filter Lubricant	
12	Filter Media Upper Containment		Filter Lubricant	
13	Media Support and Flow Through		Filter Lubricant	

Interaction Population | Popd Roles, Atts | 3. Reqs Att Values | Auto Pop'd Role Att Vals | Ta ...

5. Agent Populates Requirements from combination of Populated Interactions + Populated Roles, and Rules



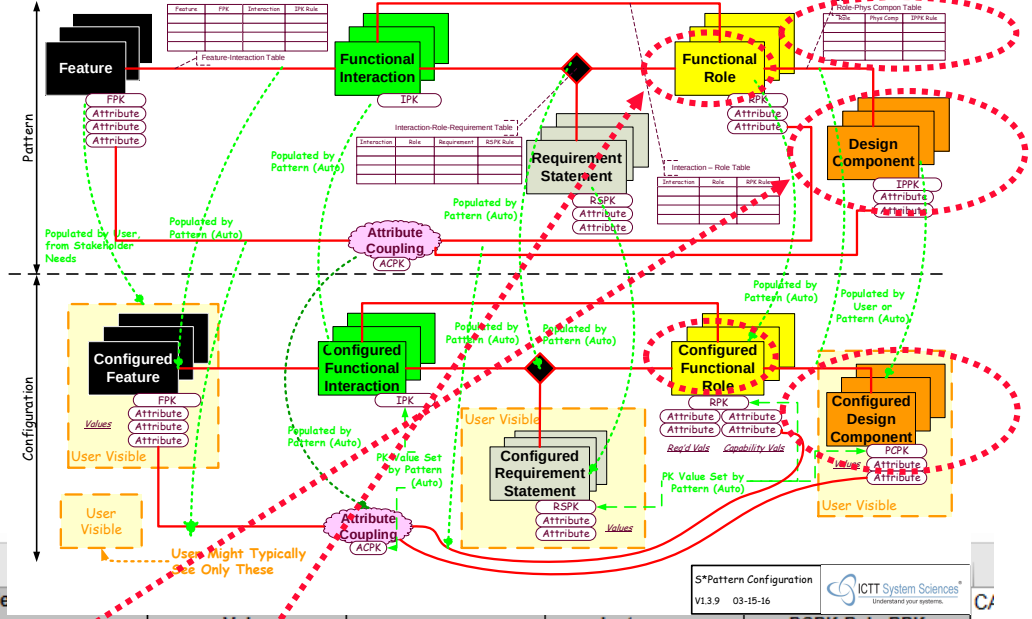
	A	E	G	H	I	J	K	L	M	N
1	Features	Interaction	Interaction PK Value	Functional Role	Role PK Value	Req ID	Req PK Value	Requirement	Functional Failure (Reverse Requirement)	Requirement Rationale
2	Filter Application[Commercial Automotive], Reliability Feature[]	Filter Lubricant		Oil Filter System		OF-52		The Oil Filter shall accommodate a Lubricant flow rate of [Lubricant Flow Rate] under the conditions of the Filtering Table.	The Oil Filter <<FAILS TO>> accommodate a Lubricant flow rate of [Lubricant Flow Rate] under the conditions of the Filtering Table.	
3	Filter Application[Commercial Automotive], Reliability Feature[]	Filter Lubricant				OF-50		For a Return Lubricant stream of [Lubricant Viscosity Range] and [Lubricant Pressure Range], the Oil Filter shall separate Filtered Contaminant particles from the Lubricant output stream, according to the [Filter Particle Size Distribution Profile].		
4	Filter Application[Commercial Automotive], Reliability Feature[]	Filter Lubricant		Oil Filter System		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].		
5	Filter Application[Commercial Automotive], Reliability Feature[]	Filter Lubricant		Oil Filter System		FL_1		For an Input Oil Stream, the Oil Filter shall separate particles from the Output Oil Stream, according to the Filtration Table.	For an Input Oil Stream, the Oil Filter <<FAILS TO>> separate particles from the Output Oil Stream, according to the Filtration Table.	
6	Filter Application[Commercial Automotive], Reliability Feature[]	Filter Lubricant		Oil Filter System		FL_2		The Oil Filter shall operate at the lubricant pressure, structural failure rates, and in-service life listed in the Filtration Table.	The Oil Filter <<FAILS TO>> operate at the lubricant pressure, structural failure rates, and in-service life listed in the Filtration Table.	
7	Filter Application[Commercial Automotive], Reliability Feature[]	Filter Lubricant		Backflow Preventer		0		During lubricant flow other than transients in lubricant pressure during shutdown or start up, the system shall permit forward lubricant flow as shown in the Pressure Drop Budget Table.	During lubricant flow other than transients in lubricant pressure during shutdown or start up, the system <<FAILS TO>> permit forward lubricant flow as shown in the Pressure Drop Budget Table.	
8	Filter Application[Commercial Automotive], Reliability Feature[]	Filter Lubricant		Solid Contaminant Separator		FL_1.1		For an Input Oil Stream, the Solid Contaminant Separator shall separate particles from the Output Oil Stream, according to the Filtration Table.	For an Input Oil Stream, the Solid Contaminant Separator <<FAILS TO>> separate particles from the Output Oil Stream, according to the Filtration Table.	
9	Filter Application[Commercial Automotive], Reliability Feature[]	Filter Lubricant		Solid Contaminant Separator		FL_2.1		The Solid Contaminant Separator shall operate at the lubricant pressure, structural failure rates, and in-service life listed in the Filtration Table.	The Solid Contaminant Separator <<FAILS TO>> operate at the lubricant pressure, structural failure rates, and in-service life listed in the Filtration Table.	

Configuration -15-16

ICTT System Sciences
Understand your systems.

Interaction Population | Popd Roles, Atts | 3. Reqs Att Values | Auto Pop'd Role Att Vals | Ta ...

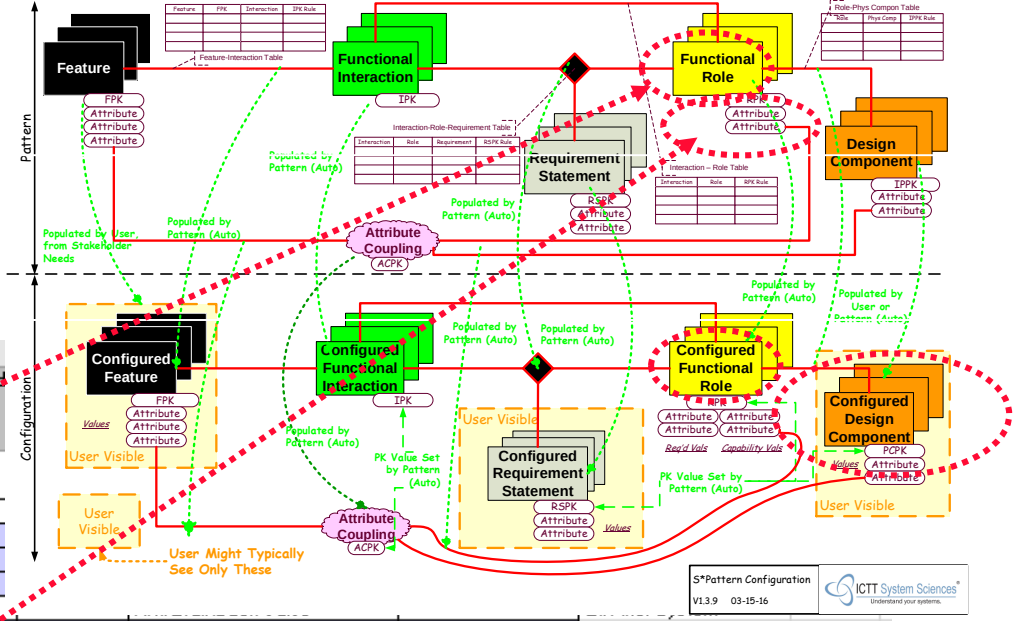
6. Agent populates Design Components, based on Populated Roles, and Rules



	A	B	C				
1	Design Component	DC Primary Key Value	Functional Role	Value		Instances	DCPK-Role-RPK Instances
2	Assembled Filter		Exterior Containment Subsystem		Oil Filter System	FALSE	TRUE
3	Assembled Filter		Oil Filter System		Oil Filter System	TRUE	TRUE
4	Base Plate		Base-Shell Attachment and Seal		Oil Filter System	TRUE	TRUE
5	Base Plate		Exterior Base Containment		Oil Filter System	FALSE	TRUE
6	Bonded Media Assy		Solid Contaminant Separator		Oil Filter System	TRUE	TRUE
7	Central Perforated Tube		Media Support and Flow Through		Oil Filter System	TRUE	TRUE
8	End Cap, Lower		Filter Media Lower Containment		Oil Filter System	TRUE	TRUE
9	Exterior Case		Exterior Shell Containment		Oil Filter System	TRUE	TRUE
10	Installation Sealing Ring Gasket		Installation Interface Gasketing		Oil Filter System	TRUE	TRUE
11	Lower Bonding Compound		Filter Media Lower Bond		Oil Filter System	TRUE	TRUE
12	Pleated Filter Media		Filter Media		Oil Filter System	TRUE	TRUE
13	Support Spring		Upper Support		Oil Filter System	TRUE	TRUE
14	Upper Bonding Component		Filter Media Upper Bond		Oil Filter System	TRUE	TRUE
15	Upper End Cap, With Valve		Filter Media Upper Containment		Oil Filter System	TRUE	TRUE
16	Upper End Cap, With Valve		Overpressure Bypass Path		Oil Filter System	FALSE	TRUE
30	Base Plate		Base-Shell Attachment and Seal		Oil Filter System	TRUE	TRUE
31	Base Plate		Exterior Base Containment		Oil Filter System	FALSE	TRUE
32	Exterior Case		Exterior Shell Containment		Oil Filter System	TRUE	TRUE
33	Installation Sealing Ring Gasket		Installation Interface Gasketing		Oil Filter System	TRUE	TRUE
34	Support Spring		Upper Support		Oil Filter System	TRUE	TRUE
500							
501							
502							

Table of Tables | Table Guide | Requirement Attribute Tables | Popd Compons, Roles | Phys ...

6. Agent populates Role Attribute (value slots), based on Populated Roles

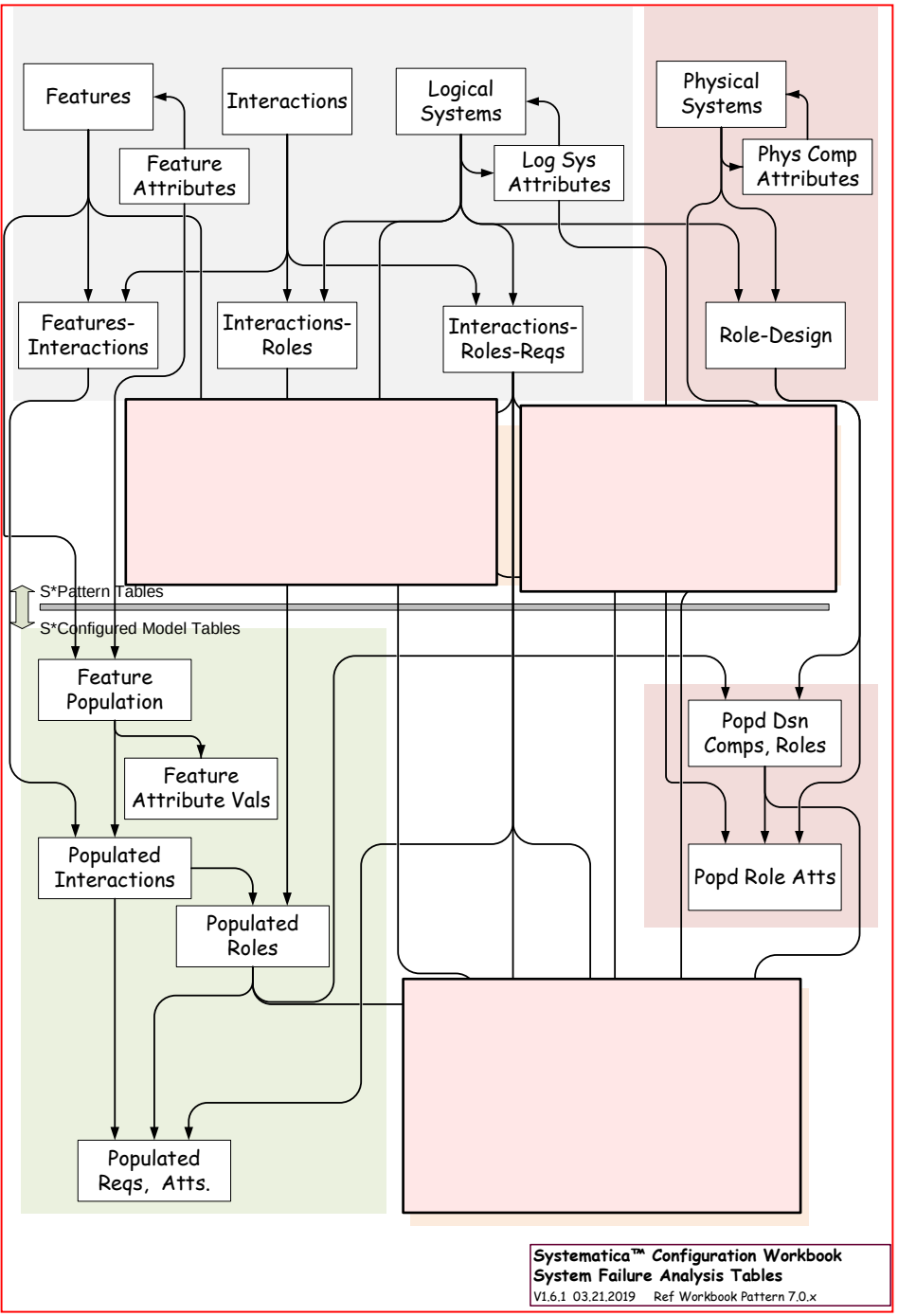


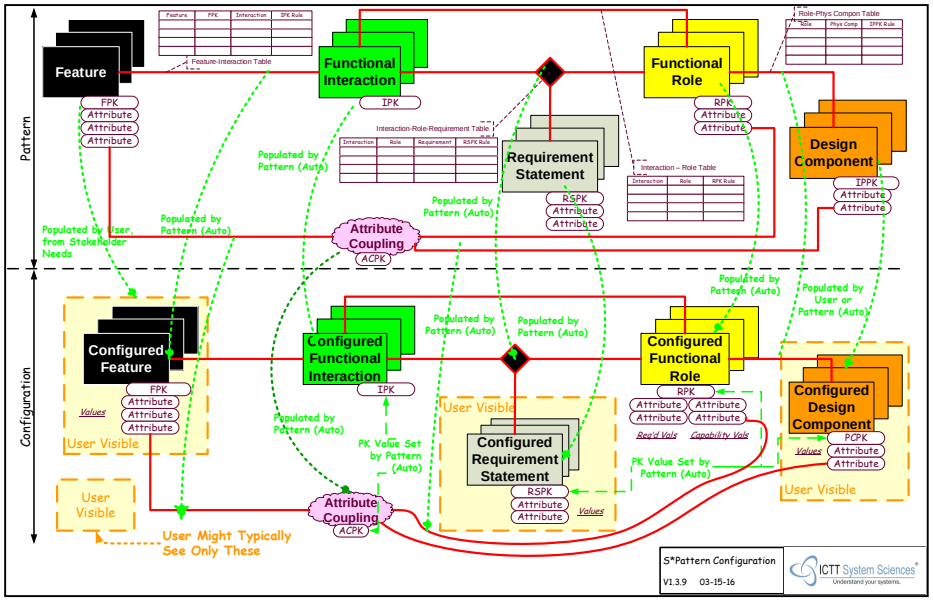
	A	B	C	D	E				
1	Logical Component Role	RPK	RSPK	Role Attribute	Required Value				
2	Exterior Containment Subsystem			#N/A					
3	Oil Filter System			#N/A					
5	Thermal Energy Distributor			#N/A					
136	Thermal Energy Distributor			#N/A					
267	Thermal Energy Distributor			#N/A					
397	Backflow Preventer			#N/A					
398	Solid Contaminant Separator			#N/A			Bonded Media Assy		Oil Filter System
399	Filter Media			Filter Efficiency at 80 Microns			Pleated Filter Media		Oil Filter System
400	Filter Media			Filter Efficiency at 60 Microns			Pleated Filter Media		Oil Filter System
401	Filter Media			Filter Efficiency at 40 Microns			Pleated Filter Media		Oil Filter System
402	Filter Media			Filter Efficiency at 30 Microns			Pleated Filter Media		Oil Filter System
403	Filter Media			Filter Efficiency at 20 Microns			Pleated Filter Media		Oil Filter System
404	Filter Media			Filter Efficiency at 15 Microns			Pleated Filter Media		Oil Filter System
405	Filter Media			Filter Efficiency at 10 Microns			Pleated Filter Media		Oil Filter System
406	Filter Media			Filter Impurity Storage Capacity			Pleated Filter Media		Oil Filter System
407	Filter Media			Minimum Failure Pressure			Pleated Filter Media		Oil Filter System
408	Filter Media			Surface Area			Pleated Filter Media		Oil Filter System
409	Filter Media			Beta Ratio			Pleated Filter Media		Oil Filter System
410	Filter Media Lower Bond			#N/A			Lower Bounding Compound		Oil Filter System
411	Filter Media Lower Containment			#N/A			End Cap, Lower		Oil Filter System
412	Filter Media Upper Bond			#N/A			Upper Bonding Component		Oil Filter System
413	Overpressure Bypass Path			#N/A			Upper End Cap, With Valve		Oil Filter System
414	Filter Media Upper Containment			#N/A			Upper End Cap, With Valve		Oil Filter System
415	Media Support and Flow Through			#N/A			Central Perforated Tube		Oil Filter System
416	Overpressure Bypass Path			#N/A			Upper End Cap, With Valve		Oil Filter System
417	Filter Media Upper Containment			#N/A			Upper End Cap, With Valve		Oil Filter System
418	Exterior Containment Subsystem			#N/A			Assembled Filter		Oil Filter System
419	Oil Filter System			#N/A			Assembled Filter		Oil Filter System
421	Thermal Energy Distributor			#N/A					Oil Filter System
552	Thermal Energy Distributor			#N/A					Oil Filter System
601									
602									

Requirement Attribute Tables | Popd Compons, Roles | Phys Allocs | Feature_Impacts | Failur ...

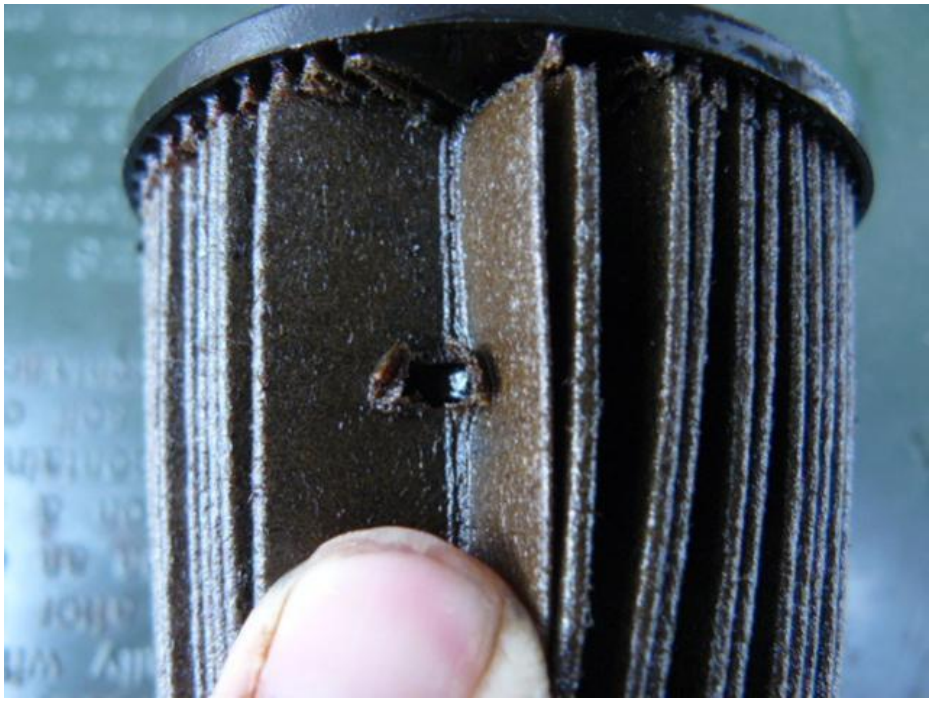
Configuration of Pattern: Mapped onto SE Workbook Tabs

Workbook Tab Names



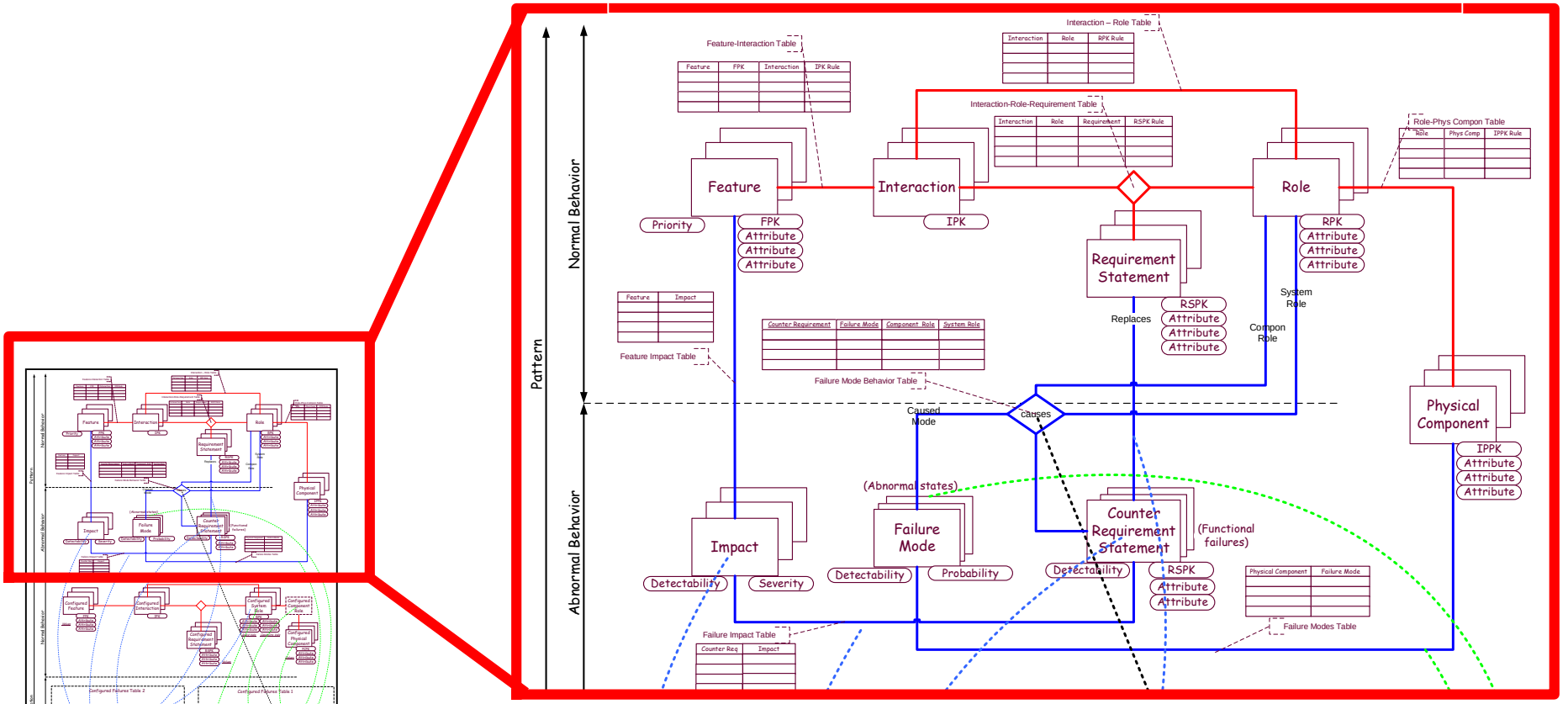


Failure Modes and Effects Analysis (FMEA), generated from the same MBSE Pattern

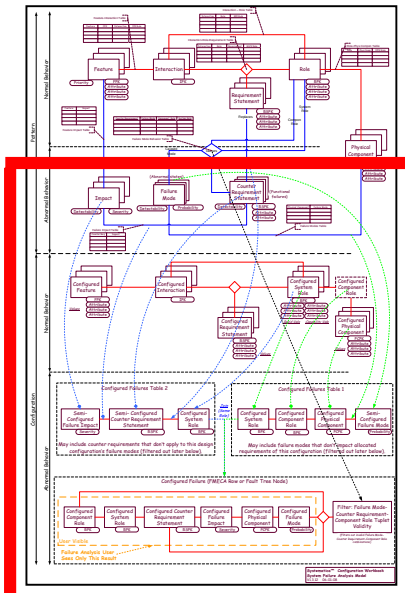


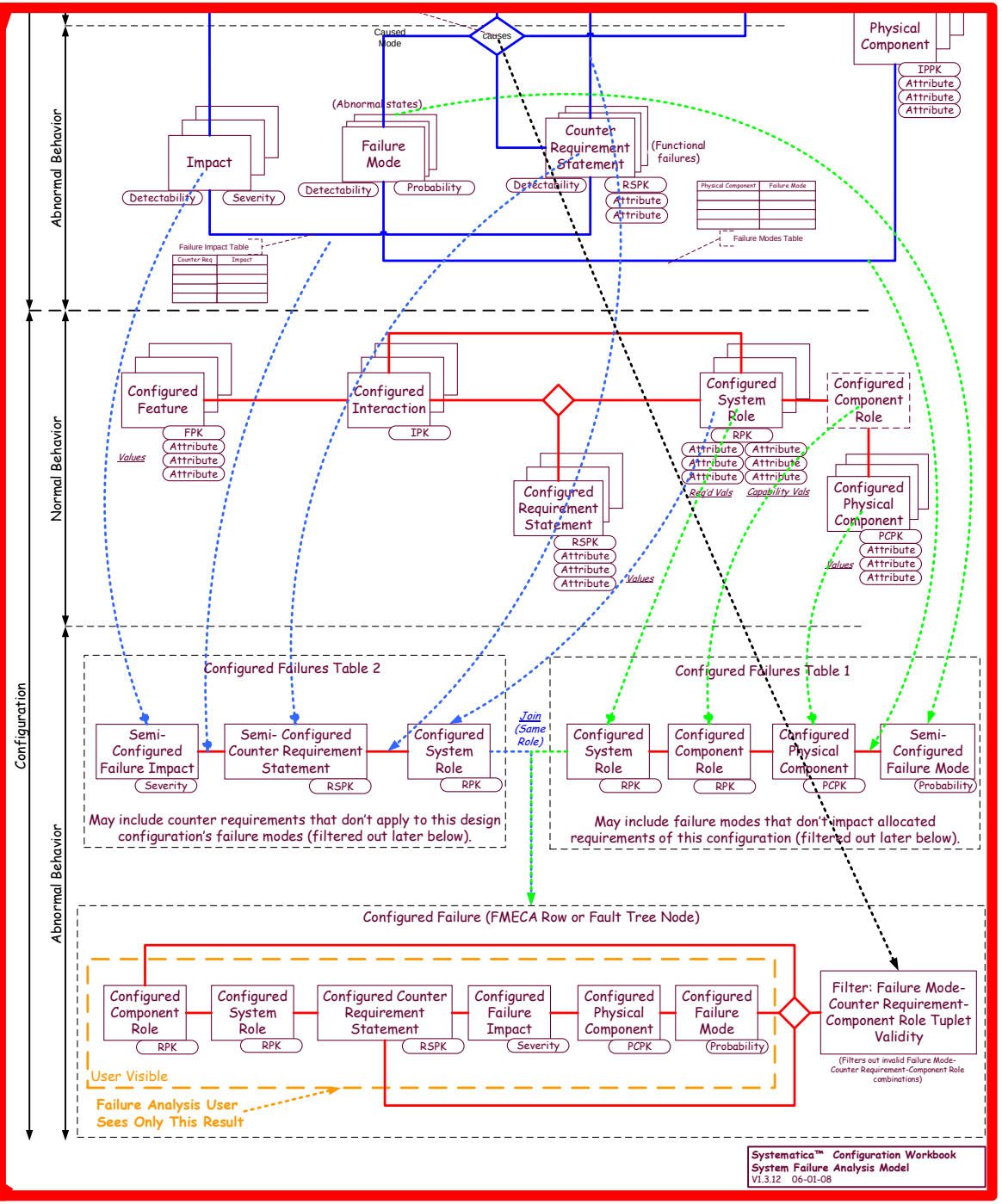
FMEA Generation, Using S*Pattern

FMEA Section of S*Metamodel

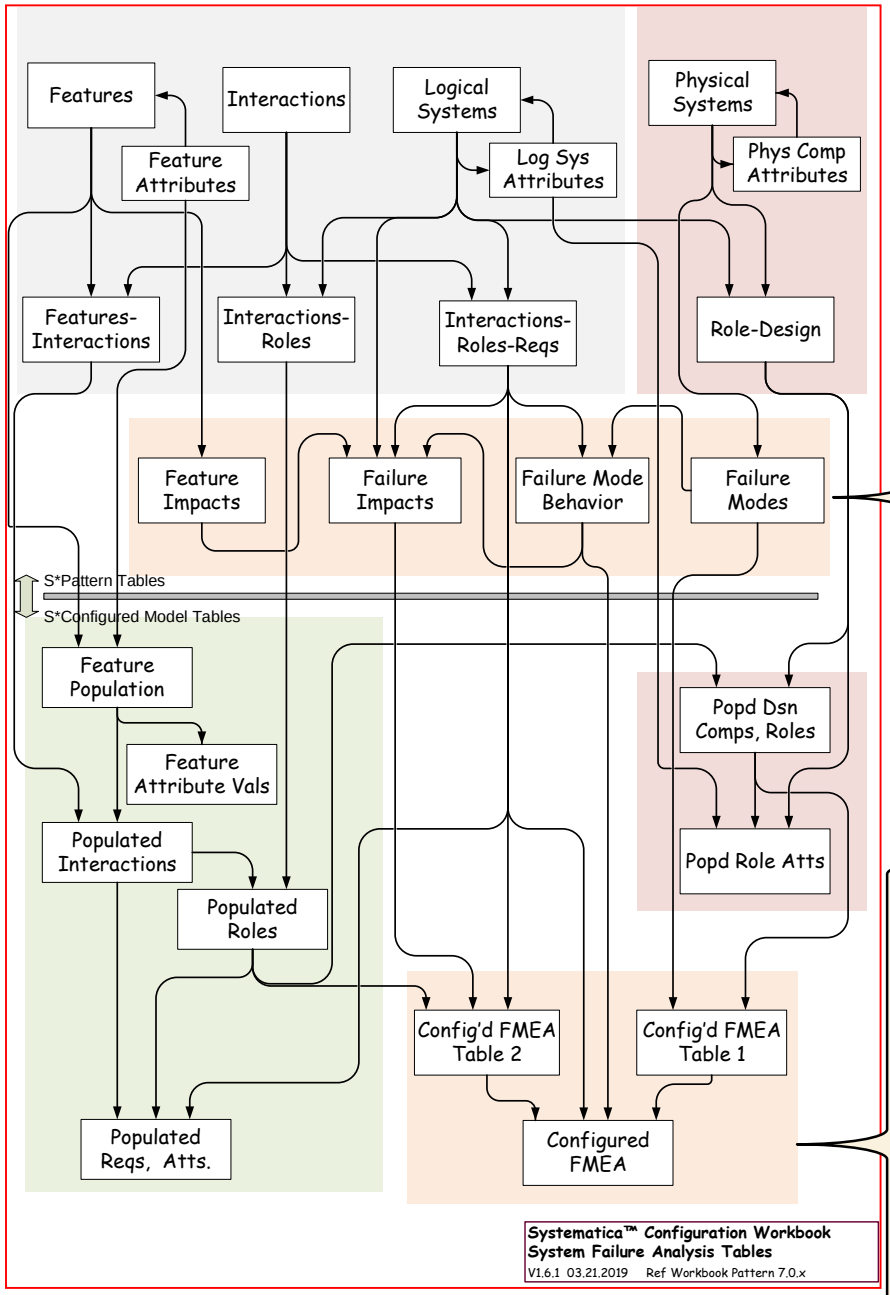


FMEA Generation, Using S*Pattern

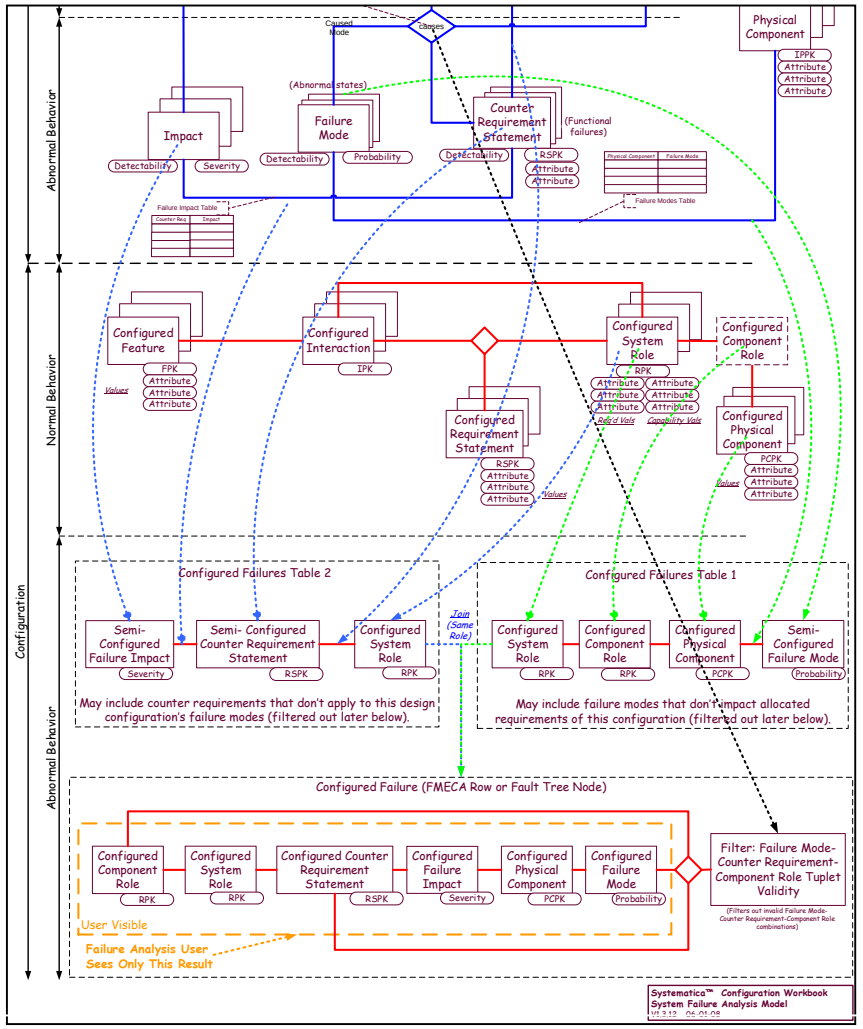




FMEA Generation, mapped onto workbook tab names



Workbook Tab Names



Generic S*FMEA Algorithm

Failure Modes of Design Components

	A	B	C	D	E	F	I
1	No Component	Component	Physical Failure Mode	Interaction Causing Failure Mode	No. of Interaction-Role Pair Slots	Duplicate of Above	Mode Not In Failure Mode Behaviors Table
2		Pleated Filter Media	Filter Media Rupture	Filter Lubricant			
3		Installation Sealing Ring Gasket	Rubber Gasket Failure				
4		Lower Bounding Compound	Bond Seal Failure				
5		Upper Bonding Component	Bond Seal Failure				
6		Anti Drainback Valve	Backflow Seal Rupture	Filter Lubricant			
7		Upper End Cap, With Valve	Low Pressure Open				
8		Pleated Filter Media	Filter Media Particle Profile Fail				
9		Upper End Cap, With Valve	Overpressure Failed Closed				
10							

Feature_Impacts | Failure Impacts | Failure Mode Behaviors | Failure_Modes | Configured Fail ...

Failure Mode Behaviors (Counter-Requirements)

	A	C	D	F	G	H	I	J	Z	AA	AB
1	Counter Requirement	Requirement ID	Failure Mode	Logical System Role	Logical Component Role	IPPK Value	Approval Status	Counter Req Row #	Sys Role-Compon Role Pair not in Role-Des Tbl	Sys Role-Compon Role-Phys Part Set not in Role-Des Tbl	Not In Current Configured System Failure
2	For an Input Oil Stream, the Oil Filter <<FAILS TO>> separate particles from the Output Oil Stream, according to the Filtration Table.	FL_1	Filter Media Rupture	Oil Filter System	Filter Media			41			
3	The Solid Contaminant Separator <<FAILS TO>> operate at the lubricant pressure, structural failure rates, and in-service life listed in the Filtration Table.	FL_2.1	Rubber Gasket Failure	Oil Filter System	Installation Interface Gasketing			44			
4	The Oil Filter <<FAILS TO>> operate at the lubricant pressure, structural failure rates, and in-service life listed in the Filtration Table.	FL_2	Bond Seal Failure	Oil Filter System	Filter Media Upper Bond			42		1	
5	During lubricant flow other than transients in lubricant pressure during shutdown or start up, the system <<FAILS TO>> permit forward lubricant flow as shown in the Pressure Drop Budget Table.	0	Bond Seal Failure	Oil Filter System	Filter Media Lower Bond			21			
6	During lubricant flow stoppage transient following shutdown, the system <<FAILS TO>> prevent backflow of lubricant into the Lubricated System.	0	Backflow Seal Rupture	Oil Filter System	Backflow Preventer			59			
7	When the hydraulic pressure drop across the Oil Filter is less than the Bypass Threshold in the Filtration Table, the Oil Filter <<FAILS TO>> restrict flow to through the Filtration Media, accomplishing filtration.	0	Low Pressure Open	Oil Filter System	Overpressure Bypass Path			6			
8	For an Input Oil Stream, the Oil Filter <<FAILS TO>> separate particles from the Output Oil Stream, according to the Filtration Table.	FL_1	Filter Media Particle Profile Fail	Oil Filter System	Filter Media			41			
9	When the hydraulic pressure drop across Oil Filter exceeds the Bypass Threshold in the Filtration Table, the Oil Filter <<FAILS TO>> activate an internal flow path bypassing the Filtration Media and filtration function.	0	Overpressure Failed Closed	Oil Filter System	Overpressure Bypass Path			5			
10	When operating within its rated lubricant pressure and temperature, at altitudes not exceeding [Max Service Altitude], the system <<FAILS TO>> maintain Fluid Leakage to the surrounding space below [Max Fluid Leakage Rate].	OF-104	Rubber Gasket Failure	Oil Filter System	Exterior Containment Subsystem			58		1	
11								#N/A			
12								#N/A			
13								#N/A			
14								#N/A			
15								#N/A			

Feature_Impacts | Failure Impacts | **Failure Mode Behaviors** | Failure_Modes | Configured Fail ...

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Negative Effects of Feature Loss

	A	B	D
1	**Feature**	**Feature Impact**	**Approval Status**
2	Filter Application	Shortened Equipment Life	
3	Reliability Feature	Premature Filter Replacement Cost and Downtime	
4	Health & Safety	Injury to Personnel from Overpressure Event	
5	Environmentally Friendly Feature	Injury to Environment from Spills and Leakage	
6			
7			
8			
9			
10			
11			
12			
13			
14			

... Feature_Impacts | Failure Impacts | Failure Mode Behaviors | Failure_Modes | Configured Fail ...

Negative Effects of Counter-Requirements

	B	C	D	E	F
1	Counter Requirement (Functional Failure)	Feature Impact	Impacted Feature	Logical Role	Status
3	When the hydraulic pressure drop across the Oil Filter is less than the Bypass Threshold in the Filtration Table, the Oil Filter <<FAILS TO>> restrict flow to through the Filtration Media, accomplishing filtration.	Shortened Equipment Life	Filter Application	Overpressure Bypass Path	
4	For an Oil Filter in the Installed state, the Installation Interface Gasketing <<FAILS TO>> conform to the adjacent joined surfaces, not providing a Local Surface Pressure in the range shown in the Seals Table.			Installation Interface Gasketing	
5	During lubricant flow other than transients in lubricant pressure during shutdown or start up, the system <<FAILS TO>> permit forward lubricant flow as shown in the Pressure Drop Budget Table.	Shortened Equipment Life	Filter Application	Backflow Preventer	
6	The bonding material <<FAILS TO>> fully cover and conform to the two component surfaces, and bond them mechanically under operating pressure.	Shortened Equipment Life	Filter Application	Filter Media Lower Bond	
7	The bonding material <<FAILS TO>> prevent flow of pressurized lubricant between the bonded components.	Shortened Equipment Life	Filter Application	Filter Media Lower Bond	
8	The Filter Media Lower Containment <<FAILS TO>> be impervious to flow of lubricant through it, at pressure.	Shortened Equipment Life	Filter Application	Filter Media Lower Containment	
9	The Filter Media Lower Containment <<FAILS TO>> uniformly bond to the Filter Media Lower Bond, at pressure.	Shortened Equipment Life	Filter Application	Filter Media Lower Containment	
10	The system <<FAILS TO>> uniformly bond to the Filter Media Upper Containment, at pressure	Shortened Equipment Life	Filter Application	Filter Media Upper Bond	
11	The Filter Media Upper Containment <<FAILS TO>> be impervious to flow of lubricant through it, at pressure.	Shortened Equipment Life	Filter Application	Filter Media Upper Containment	
	The system <<FAILS TO>> retain its geometric			Media Support and	

Feature_Impacts | Failure Impacts | Failure Mode Behaviors | Failure_Modes | Configured

Generated Failure Analysis (FMEA)

	A	B	C	D	E	F	G	H	I	J	K
1	Logical System Role	Role PK Value	Requirement	Counter Requirement (Functional Failure)	Failure Mode	Physical Component	Physical Component PK Value	Logical Component Role	Feature Impact (Failure Impact)	Interaction Causing Failure Mode	Filter: TRUE only if Failure Mode - Counter Req Pair Appear in Failure Mode Behaviors Tbl
27	Oil Filter System		FL_1	For an Input Oil Stream, the Oil Filter <<FAILS TO>> separate particles from the Output Oil Stream, according to the Filtration Table.	Filter Media Rupture	Pleated Filter Media		Filter Media	Shortened Equipment Life	Filter Lubricant	TRUE
30	Oil Filter System		FL_1	For an Input Oil Stream, the Oil Filter <<FAILS TO>> separate particles from the Output Oil Stream, according to the Filtration Table.	Filter Media Particle Profile Fail	Pleated Filter Media		Filter Media	Shortened Equipment Life	0	TRUE
37	Oil Filter System		FL_2	The Oil Filter <<FAILS TO>> operate at the lubricant pressure, structural failure rates, and in-service life listed in the Filtration Table.	Bond Seal Failure	Upper Bonding Component		Filter Media Upper Bond	Premature Filter Replacement Cost and Downtime	0	TRUE
501											
502											
503											
504											
505											
506											
507											
508											
509											
510											

... Configured Failures Tbl 1 | Configured Failures Tbl 2 | Configured Failure Analysis | Lists

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Implications for discussion

- Model-Based Systems Engineering (MBSE) S*Metamodel provides:
  - an information framework organizing and integrating all requirements and design information--combining partner and other source models;
  - Integrates across Product Application, Manufacturing, and other Domain Systems -- facilitates finding where the "holes" are;
  - Explicates decision-making criteria in Stakeholder Feature trade-off configuration space;
  - Unifies mathematical and prose requirements, design constraints.
- Pattern-Based Systems Engineering (PBSE):
  - Applies and extends the MBSE metamodel to describe reusable, configurable, S*Patterns of requirements and designs;
  - These can represent product platforms with configurable options;
  - They can also represent consistent Market Portfolios, Technology Portfolios, and Product Portfolios, all of which are dynamically changing;
  - PBSE is inherently enabled by starting to perform MBSE.

For additional information

ICTT System Sciences
378 South Airport Street
Terre Haute, IN 47803
812-232-2062
schindel@ictt.com