INCOSE/OMG MBSE Initiative
PBSE Patterns Challenge Team

Meeting: Nov 10, 2014

Team web site: http://www.omgwiki.org/MBSE/doku.php?id=mbse:patterns:patterns

(Schedule adjustable as needed)

Meeting Agenda: **INCOSE PBSE Patterns Challenge Team (of MBSE Initiative)**

Web Conference Meeting: Monday, November 10, 2014, 4:00 – 5:30 PM EST

General background and earlier meetings: Team web site on MBSE wiki: http://www.omgwiki.org/MBSE/doku.php?id=mbse:patterns:patterns	
Meeting start up: • Review of meeting objectives and agenda	4:00 – 4:05 PM EST

Challenge Team Current Projects, Reports:
• **Wave 1**: List of known team projects in progress underway since earlier this year
  ○ IS2015 papers that were submitted by this Patterns Challenge Team – where to find the abstracts, then papers
  ○ Time frame of these projects: Paper drafts were submitted by Nov 9; acceptances Feb 2015; finals Mar 2015
  ○ Reviews of submitted abstracts, drafts, by Challenge Team members
• **Wave 2:** Newer join-up interests of other individuals, working groups:
  ○ Time frame(s) of these Wave 2 projects
  ○ Health Care (regional WG and MBSE challenge team; Vijay Thukral, Cientive Group)
  ○ SE Social Network Pattern (Chris Hoffman, Cummins)
  ○ Agile Systems Pattern (jointly with Agile Systems WG, chaired by Rick Dove, Paradigm Shift, International)
  ○ Our challenge team is providing S*PBSE methodology summary for updated INCOSE report
• Approach to Agile Systems work of November-January, with Agile Systems WG (Rick Dove)
  ○ Joint session by our groups at IW2015, Jan 24, 2015, Los Angeles
  ○ Agile System Architectural Pattern
  ○ Additional internal role of Patterns within Agile Systems—PBSE as Agile Modeling
  ○ Historical references on Agile Systems
• (Interim) team web site file repository pages contain draft patterns in progress, pending longer-term INCOSE solution
	4:05 – 4:30

Walk-through of next segments of S*Pattern(s): • If you are newer to this S*Patterns team: Where to find information. (Do you need catch up session/sessions?) • Wave 1 sub-team pattern discussions, questions • Walk-through of an S*Patterns topic: Pattern Attributes, Attribute Couplings, Attribute Configurations (parameterization)	4:30 – 5:00
Planning Next Activities: • Alignment of next meetings to the needs of above Wave 1 and Wave 2 work • Outreach: Who else should be involved?	5:00 – 5:15
Closing: • Contact information • Adjourn	5:15

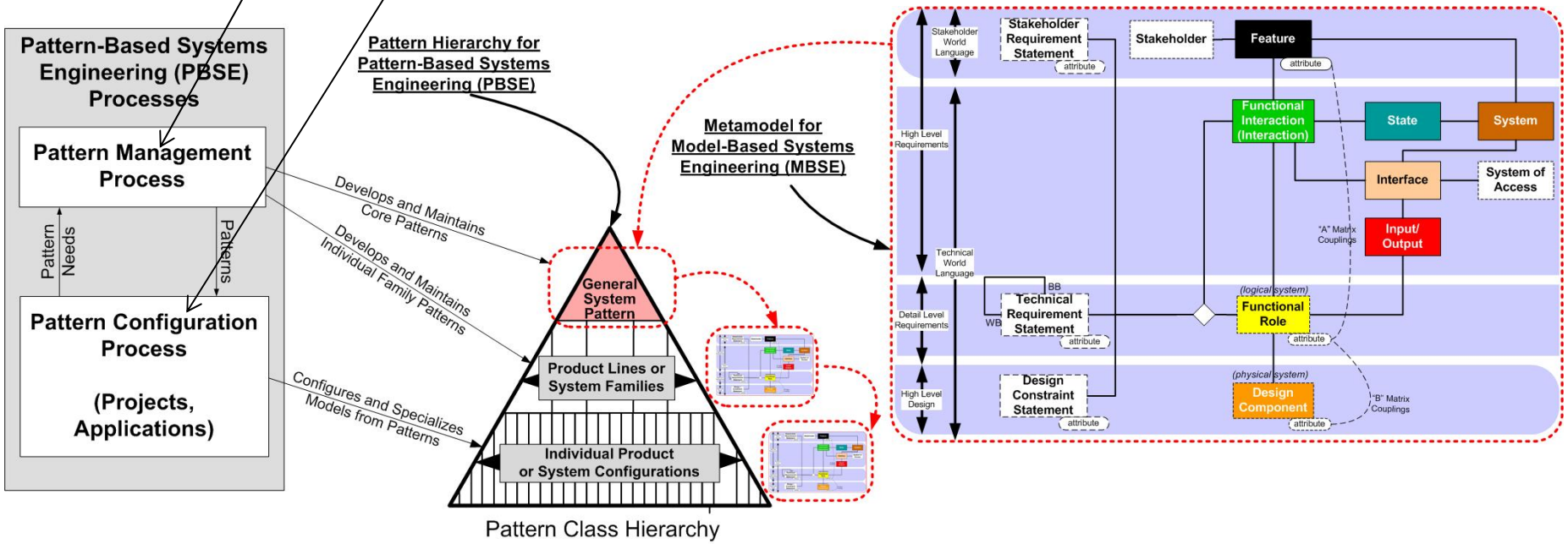
For more information, contact-- Bill Schindel schindel@ictt.com Troy Peterson peterson_troy@bah.com

Agenda--Nov 10, 2014 Mtg of PBSE Challenge Team of MBSE Initiative V1.1.1

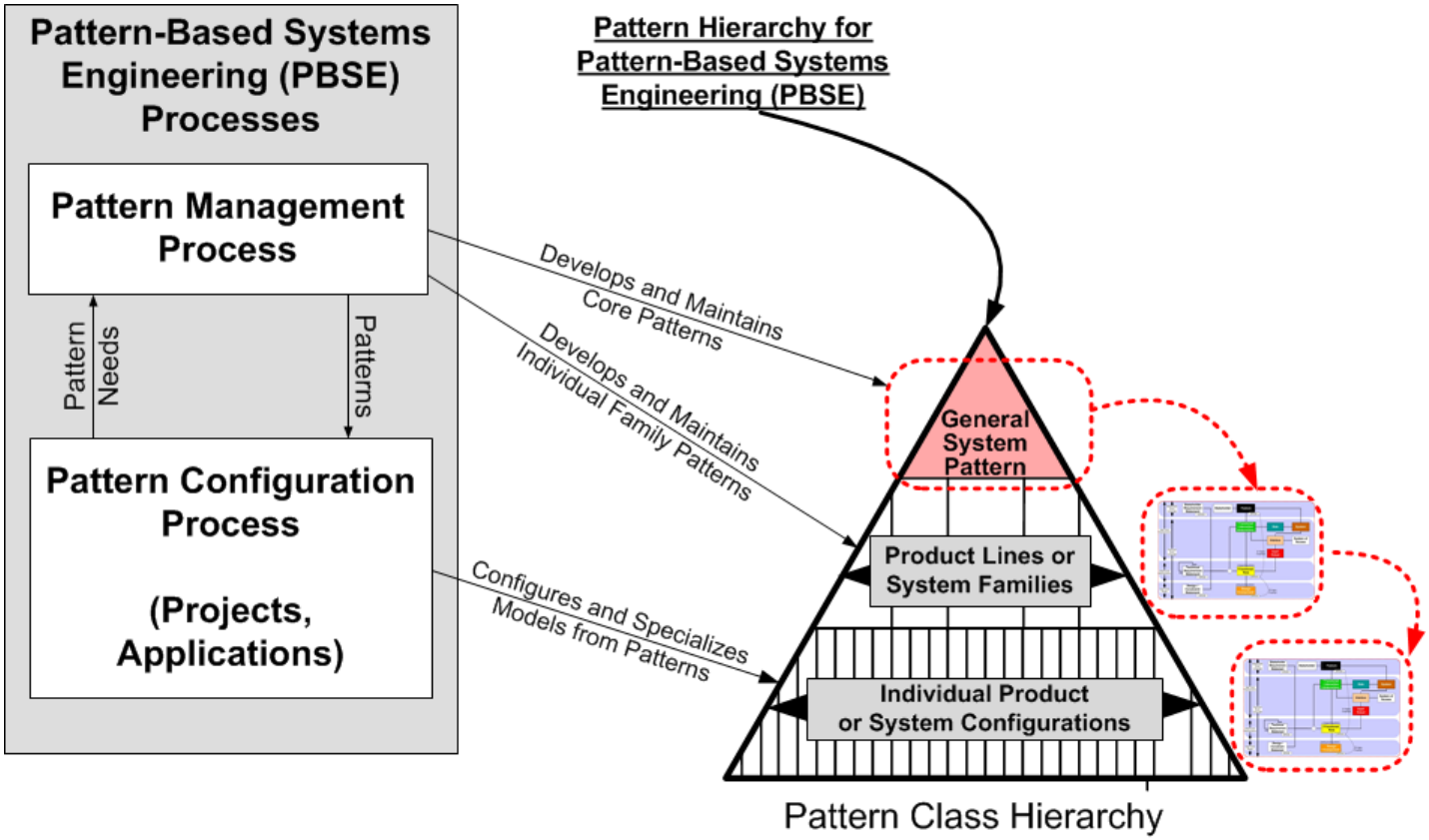
- **This Challenge Team is concerned with *configurable, re-usable system models*, called "S*Patterns":**
  - Models containing a certain minimal set of elements are called S*Models
  - May be expressed in any modeling language (e.g., SysML, or other)
  - Re-usable, configurable S*Models are called S*Patterns
  - By "Pattern-Based Systems Engineering" (PBSE) we mean MBSE enhanced by these generalized assets
  - These are system-level patterns (models of whole managed platforms), not just smaller-scale component design patterns

Pattern-Based Systems Engineering (PBSE)

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



Business process optimized for PBSE fulfill a different vision:



Why do most representations of the systems engineering process appear to assume starting from no formal knowledge about the system of interest & its domain?

Patterns Challenge Team:

These are the known pattern sub-team projects known to be underway in recent months ("Wave 1" Projects), with six papers known submitted--

☑ = *Known to have been submitted as IS2015 papers, by deadline*

- **S*Patterns:**
  - ☑ Multi-domain product/manufacturing process example (Oil Filter Family) (Bill Schindel, Stephen Lewis, Jason Sherey, Saumya Sanyal)
  - ☑ Automated Test Systems, Using MBSE/PBSE (David Cook)
  - ☑ Verification Review System Patterns (Andy Pickard & colleagues)
  - ☑ Automated Ground Vehicle System Pattern (Troy Peterson)
  - ❑ Mil/Aero Electronic Systems Pattern (Tamara Valinoto & colleagues)
- **S*Pattern Infrastructure, Methods, and Agile Systems Workshop Prep:**
  - ☑ Maps or Itineraries? (configuration space versus process, procedure)
  - ☑ Tracking System Trajectories (movement in configuration space)
- **Abstracts of all are on today's meeting web site, along with whole papers for the last two, for review by members of this team:**

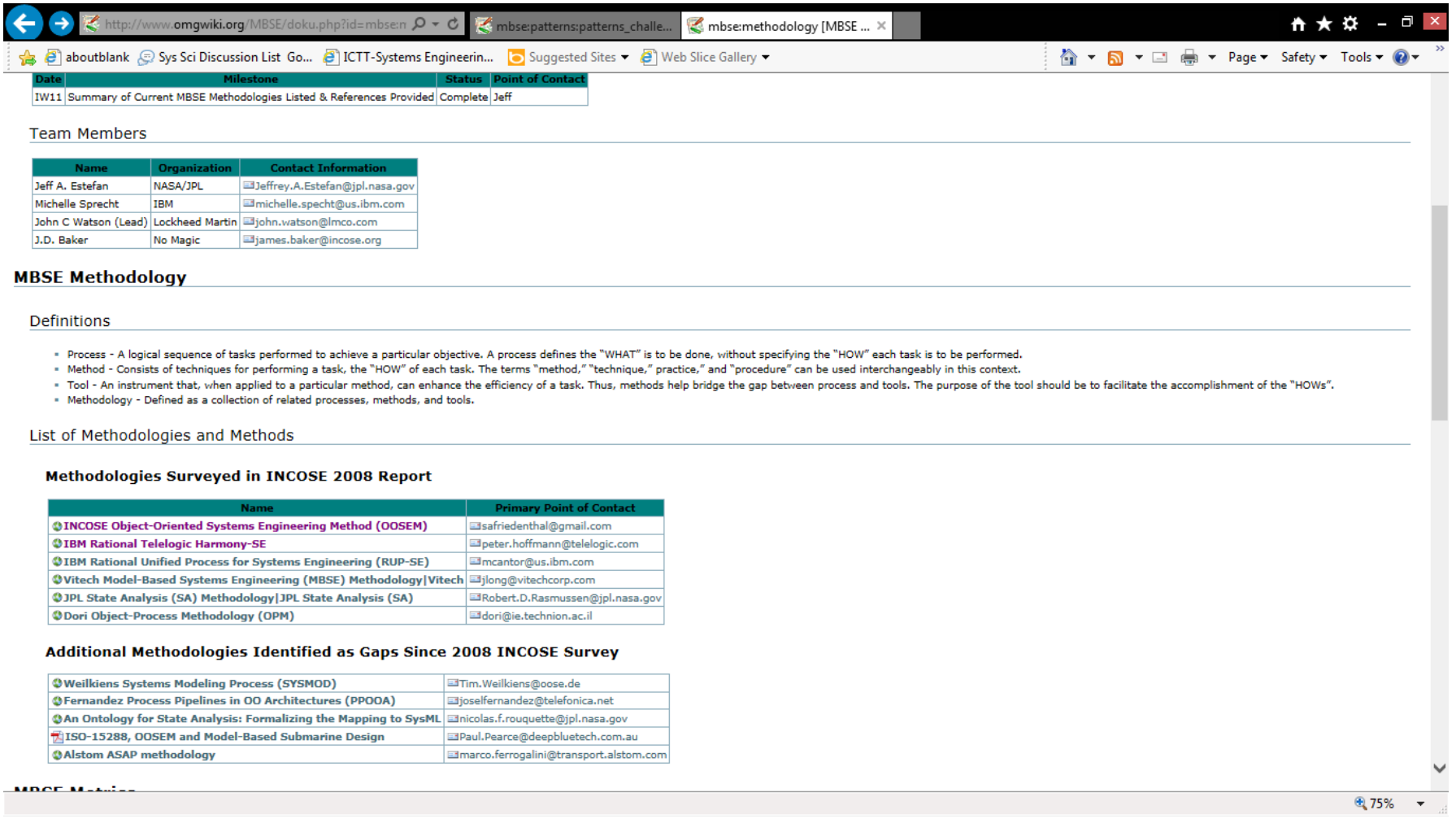
http://www.omgwiki.org/MBSE/doku.php?id=mbse:patterns:patterns_challenge_team_mtg_11.10.14

- **“Wave 2” Projects: More recent join-ups with this team, on newer / future projects:**
  - Health Care System Pattern (joint with regional WG / MBSE challenge team); Vijay Thukral, Cientive Group;
  - Systems Engineering Social Network Pattern; Chris Hoffman, Cummins
  - Agile Systems Pattern (and related MBSE workshop session at IW2015, joint with Agile Systems WG); Rick Dove, Paradigm Shift, International
  - Input on S*PBSE methodology summary for updated INCOSE methodology summary (updating 2008 “Estafan” report)
  - These S*Pattern projects are closer to their starting gate, and work will likely be Nov-Jan, or longer if appropriate.

  - Are you interested in following or involvement in any of these?

Estefan, Jeff A., "Survey of Model-Based Systems Engineering (MBSE) Methodologies," Rev. B, INCOSE Technical Publication, Document No.: INCOSE-TD-2007-003-01, International Council on Systems Engineering, San Diego, CA, June 10, 2008. http://www.incose.org/ProductsPubs/pdf/techdata/MTTC/MBSE_Methodology_Survey_2008-0610_RevB-JAE2.pdf

http://www.omgwiki.org/MBSE/doku.php?id=mbse:methodology#mbse_benchmarking_survey



http://www.omgwiki.org/MBSE/doku.php?id=mbse:n | mbse:patterns:patterns_challe... | mbse:methodology [MBSE ...

aboutblank | Sys Sci Discussion List Go... | ICTT-Systems Engineerin... | Suggested Sites | Web Slice Gallery | Page | Safety | Tools

Date	Milestone	Status	Point of Contact
IW11	Summary of Current MBSE Methodologies Listed & References Provided	Complete	Jeff

Team Members

Name	Organization	Contact Information
Jeff A. Estefan	NASA/JPL	Jeffrey.A.Estefan@jpl.nasa.gov
Michelle Sprecht	IBM	michelle.specht@us.ibm.com
John C Watson (Lead)	Lockheed Martin	john.watson@lmco.com
J.D. Baker	No Magic	james.baker@incose.org

MBSE Methodology

Definitions

- Process - A logical sequence of tasks performed to achieve a particular objective. A process defines the "WHAT" is to be done, without specifying the "HOW" each task is to be performed.
- Method - Consists of techniques for performing a task, the "HOW" of each task. The terms "method," "technique," practice," and "procedure" can be used interchangeably in this context.
- Tool - An instrument that, when applied to a particular method, can enhance the efficiency of a task. Thus, methods help bridge the gap between process and tools. The purpose of the tool should be to facilitate the accomplishment of the "HOWs".
- Methodology - Defined as a collection of related processes, methods, and tools.

List of Methodologies and Methods

Methodologies Surveyed in INCOSE 2008 Report

Name	Primary Point of Contact
INCOSE Object-Oriented Systems Engineering Method (OOSEM)	safriedenthal@gmail.com
IBM Rational Telelogic Harmony-SE	peter.hoffmann@telelogic.com
IBM Rational Unified Process for Systems Engineering (RUP-SE)	mcantor@us.ibm.com
Vitech Model-Based Systems Engineering (MBSE) Methodology|Vitech	jlong@vitechcorp.com
JPL State Analysis (SA) Methodology|JPL State Analysis (SA)	Robert.D.Rasmussen@jpl.nasa.gov
Dori Object-Process Methodology (OPM)	dori@ie.technion.ac.il

Additional Methodologies Identified as Gaps Since 2008 INCOSE Survey

Weilkiens Systems Modeling Process (SYSMOD)	Tim.Weilkiens@oose.de
Fernandez Process Pipelines in OO Architectures (PPOOA)	joselfernandez@telefonica.net
An Ontology for State Analysis: Formalizing the Mapping to SysML	nicolas.f.rouquette@jpl.nasa.gov
ISO-15288, OOSEM and Model-Based Submarine Design	Paul.Pearce@deepbluetech.com.au
Alstom ASAP methodology	marco.ferrogalini@transport.alstom.com

75%

Approach to Agile Systems w/Rick Dove & Agile Systems WG

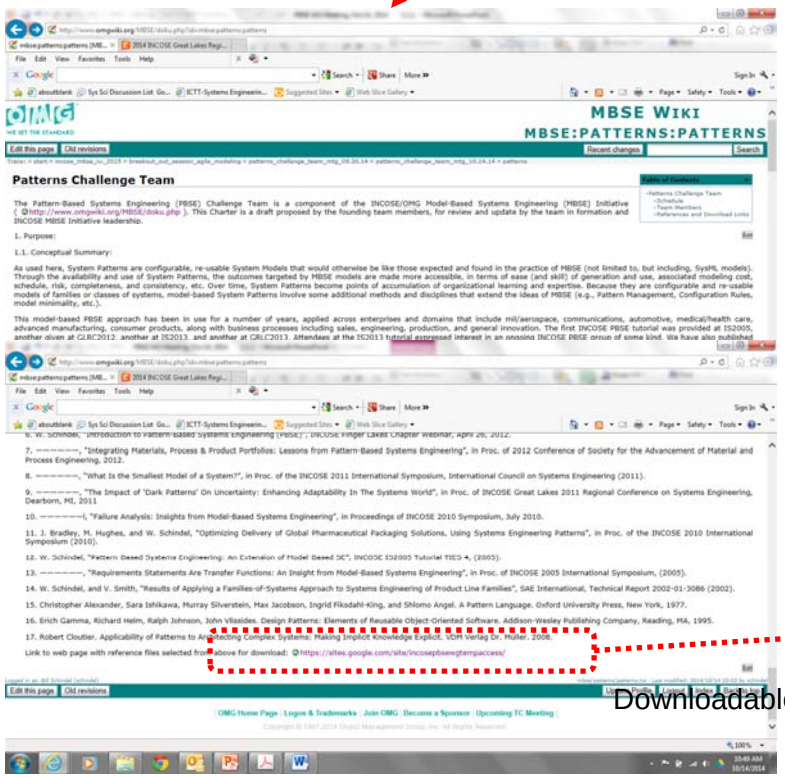
- Agreed with Rick Dove and Sandy Friedenthal that we will produce a joint break-out session during the IW2015 MBSE Workshop:
  - Title: "Agile Modeling and Modeling Agile Systems"
- In September, visited Rick in New Mexico and began work on this together.
- For an overview of this breakout session, see:
  - http://www.omgwiki.org/MBSE/doku.php?id=mbse:incose_mbse_iw_2015 and
  - http://www.omgwiki.org/MBSE/doku.php?id=mbse:incose_mbse_iw_2015:breakout_out_session_agile_modeling
- General approach:
  - For Agile Systems background, see Rick's Agile Systems Part 1 and Part 2 papers from IS2014:
    - Copies are on today's meeting web site
  - Our S*Patterns contributions:
    - Agile System Architectural S*Pattern (including ISO15288)
    - And, additional internal role of Patterns within Agile Systems (PBSE as Agile Modeling)
    - As preparation, see our two IS2015 papers on today's web site ("Maps and Itineraries"; "System Trajectories")

Team Pattern Interim Repository: New Pages Added to PBSE Challenge Team Site

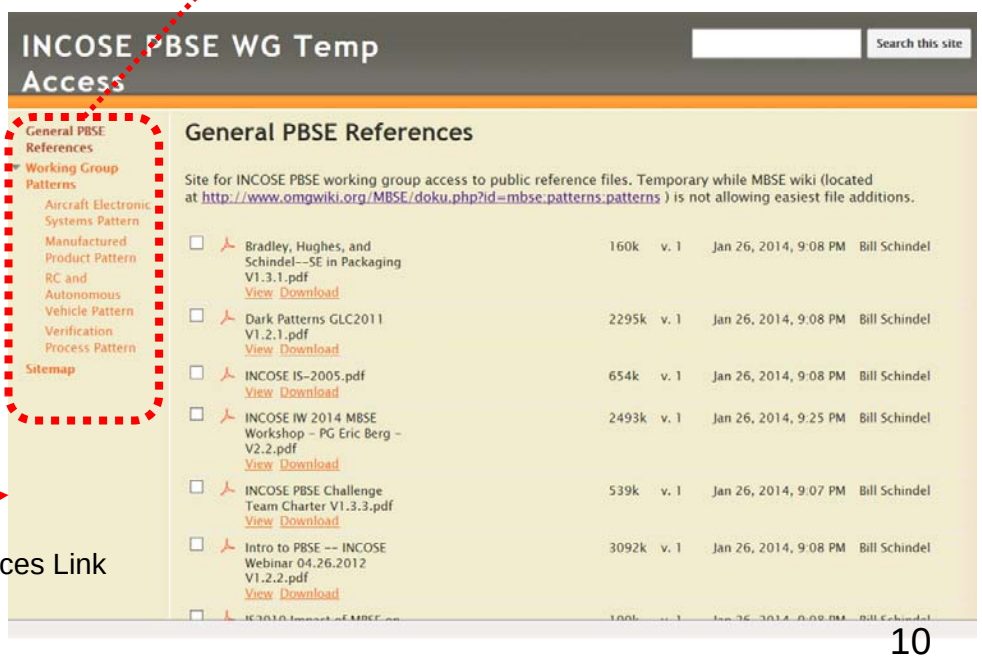
- There are now four sub-pages for storing the in-process draft patterns being worked on by this team:

NEW

Existing Team Web Page on INCOSE/OMG MBSE wiki:
http://www.omgwiki.org/MBSE/doku.php?id=mbse:patterns:patterns



https://sites.google.com/site/incosepbsewgtempaccess/



Downloadable References Link

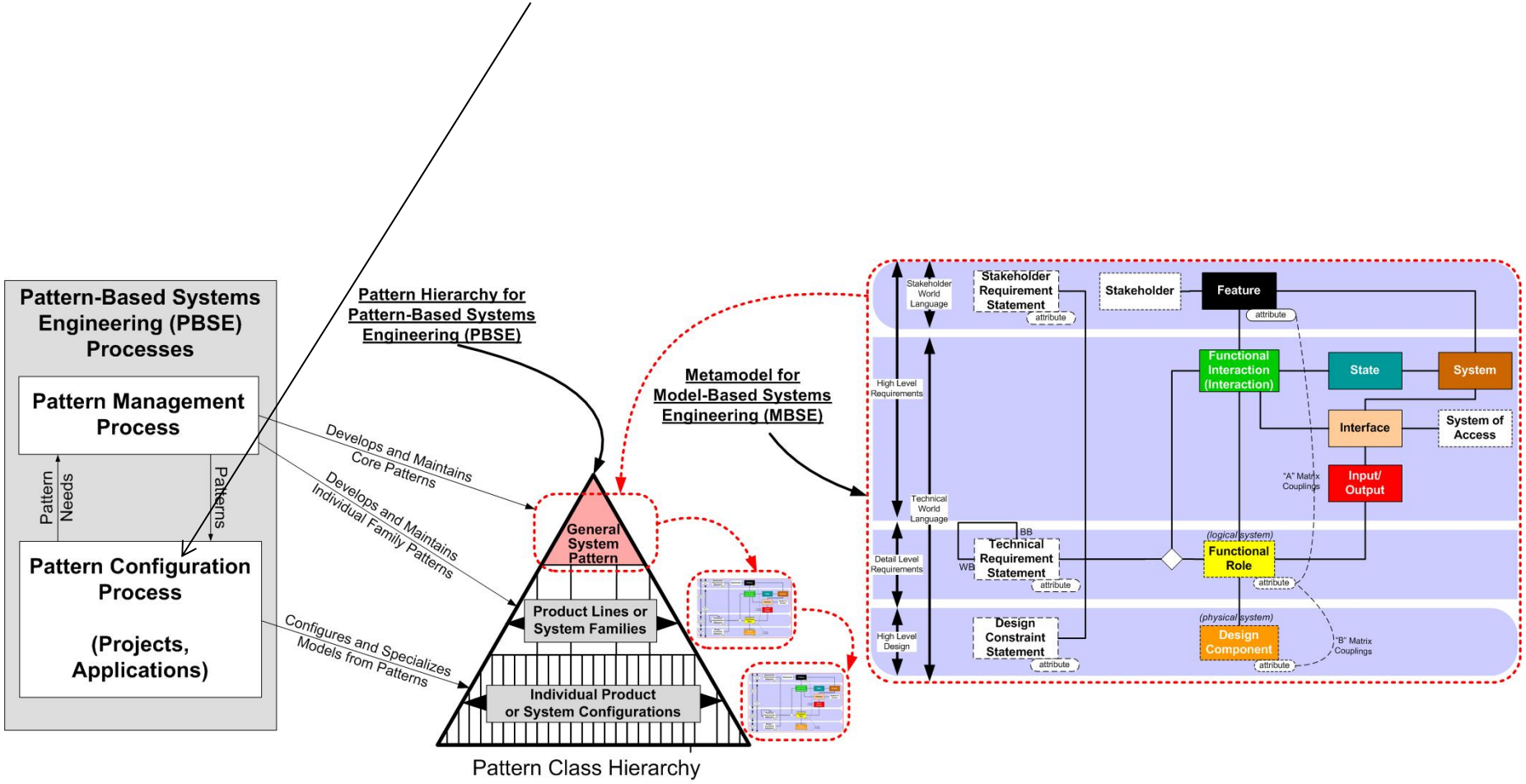
- **Team Calendar of Work and Meetings:**
  - Alignment of next meetings to the needs of Wave 1 and Wave 2 efforts.
  - Would this work?--
    - One meeting in early December
    - One meeting in early January
    - Meeting at IW in late January
  - We also want to begin planning the agenda of our team meeting at IW2015
    - Monday-Tuesday, Jan 26-27.
    - Separate from our joint workshop there on Agile Systems, Saturday, Jan 24.
  - Your thoughts?

Walk-through of next segments of S*Patterns

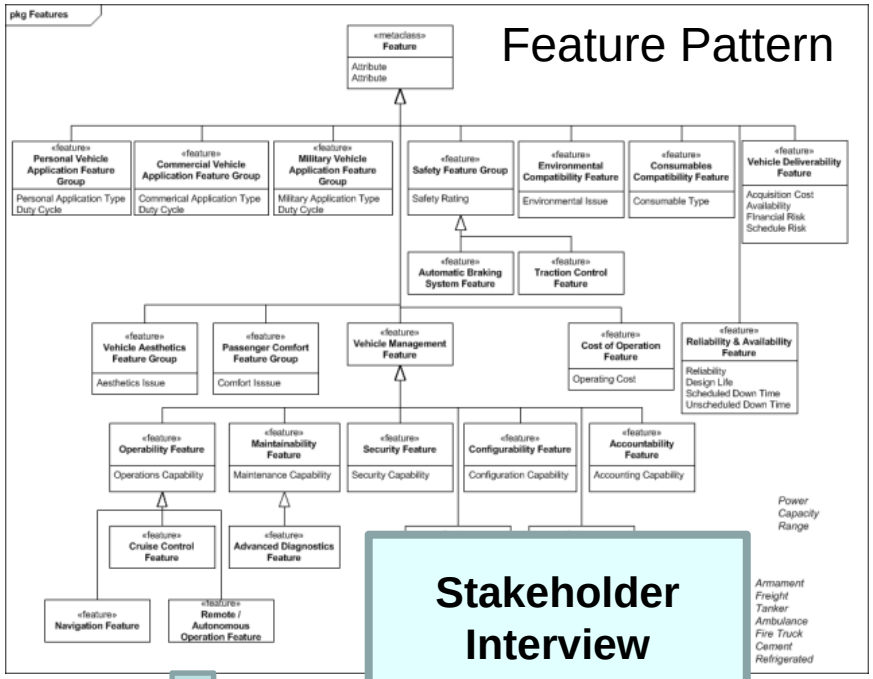
- Any discussion or question areas for current Wave 1 patterns?
  -
  -
  -
  -
- If you are new to this team, background available at:
  - General S*PBSE methodology tutorial and papers downloads, through link at bottom of team web site:
    - http://www.omgwiki.org/MBSE/doku.php?id=mbse:patterns:patterns
  - Past team meeting minutes and meeting materials, through meeting links in “Schedule” table at middle of team web site:
    - http://www.omgwiki.org/MBSE/doku.php?id=mbse:patterns:patterns

Walk-through of next segments of S*Patterns

- The Pattern Configuration Process



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



Stakeholder Requirements Document

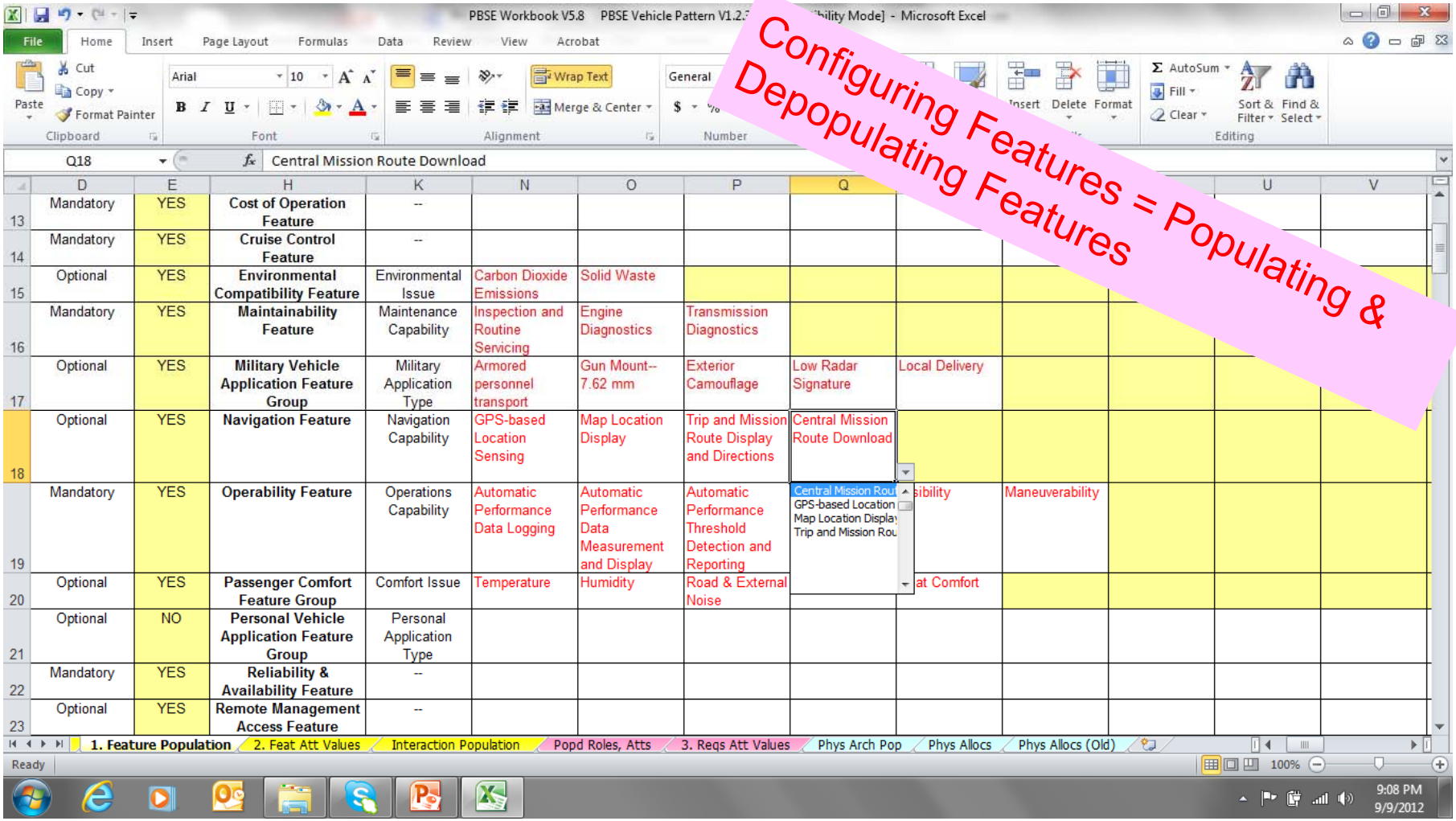
Stakeholder Interview Template

Stakeholder Interview Process

Populates the questions & issues

Generates

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



	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	Central Mission Rou GPS-based Location Map Location Displa Trip and Mission Rou	ibility	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**	--							

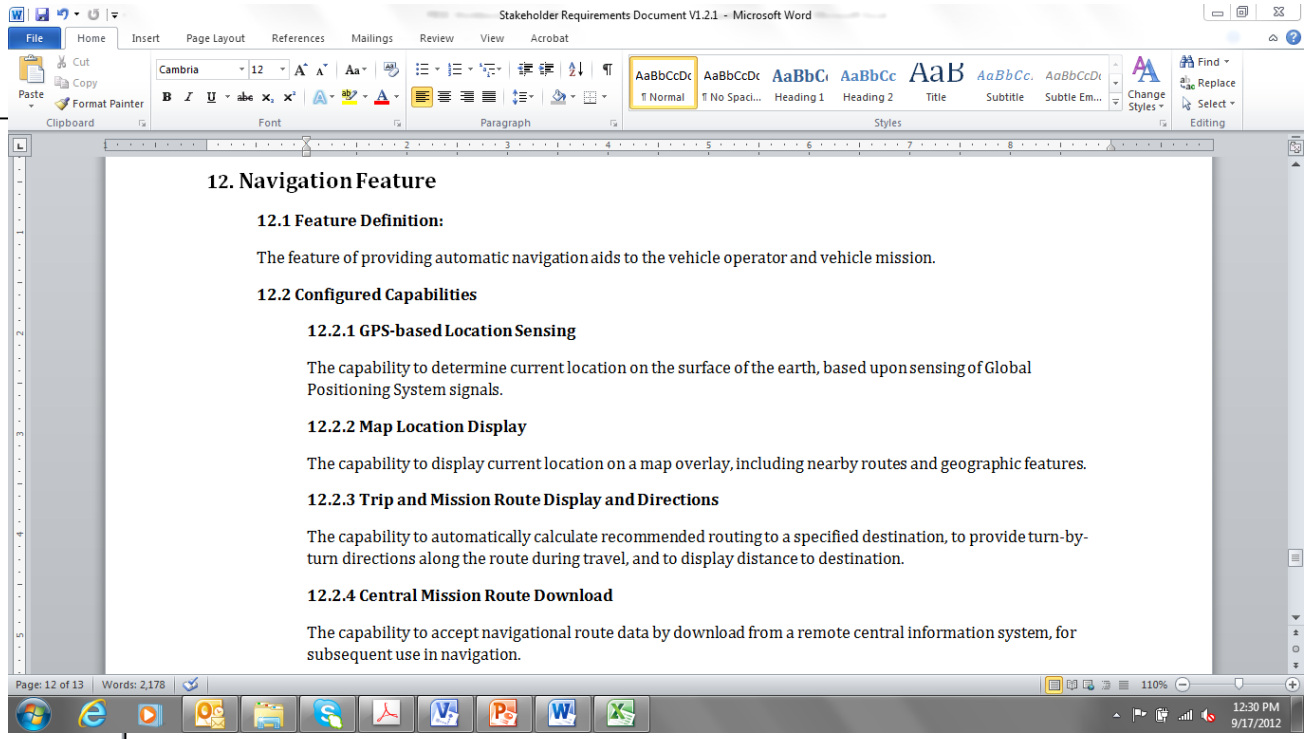
1. Using the Feature Pattern to Rapidly Capture & Validate Stakeholder Requirements: An Example

Stakeholder Requirements Document

Military Vehicle Configuration Baker

Version: 1.2.1

03 May 2012



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, 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.

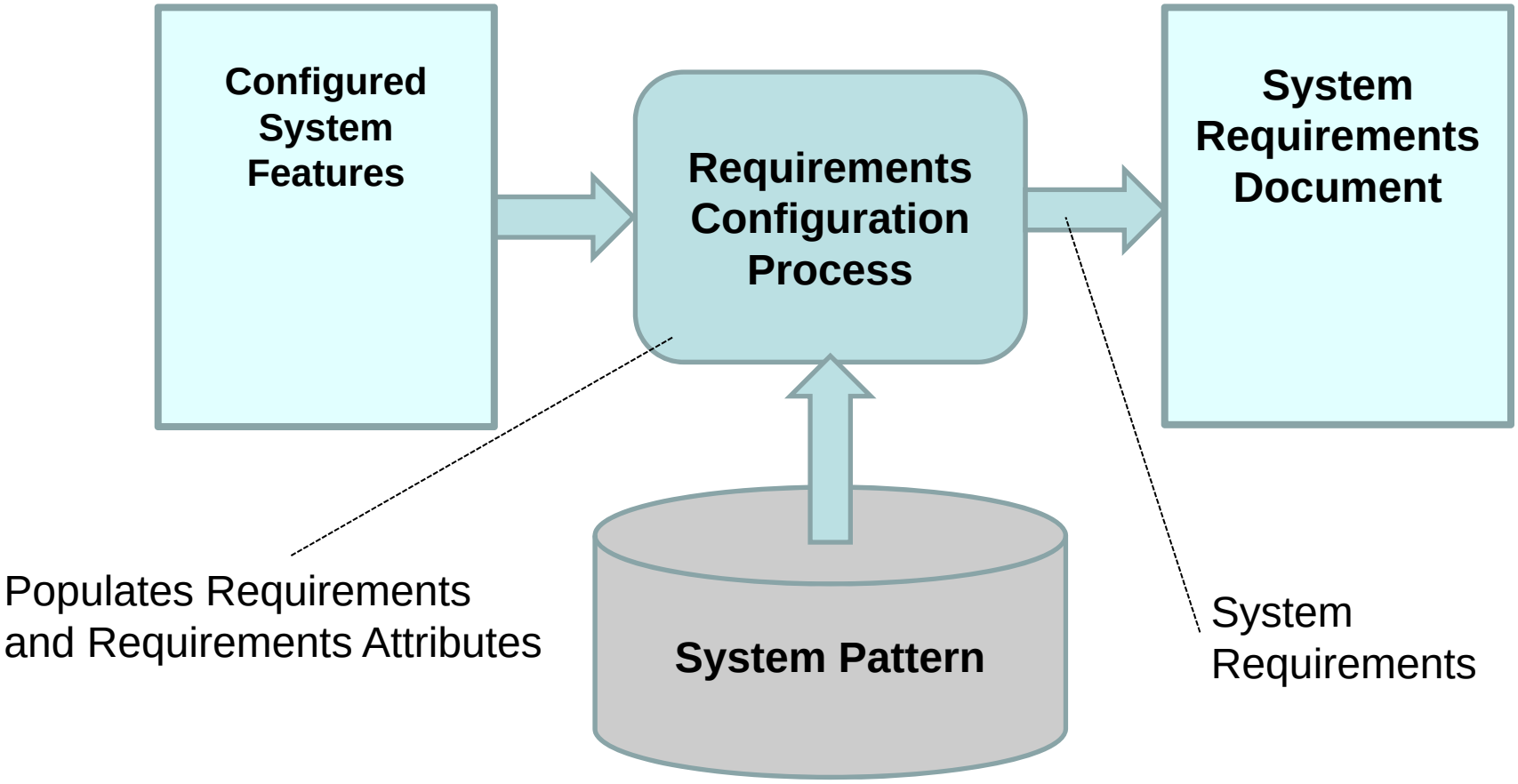
How do I know whether I have all the Features?

- This is why we use a Pattern!
  - Moves problem to the builder of the original pattern.
- 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 Stakeholders
  - 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.

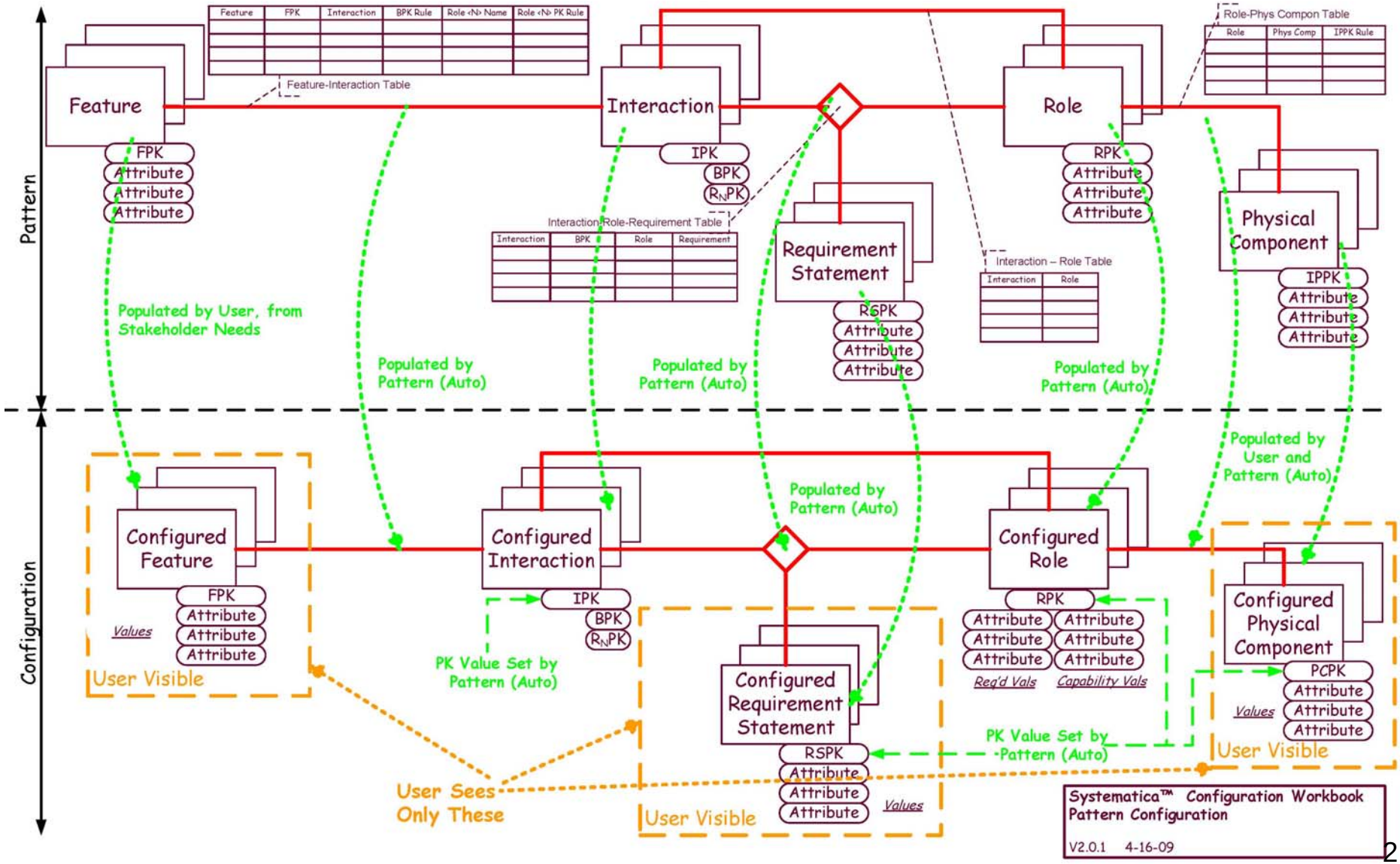
2. Using Pattern Configuration to generate better System Requirements faster: Example

- 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.

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

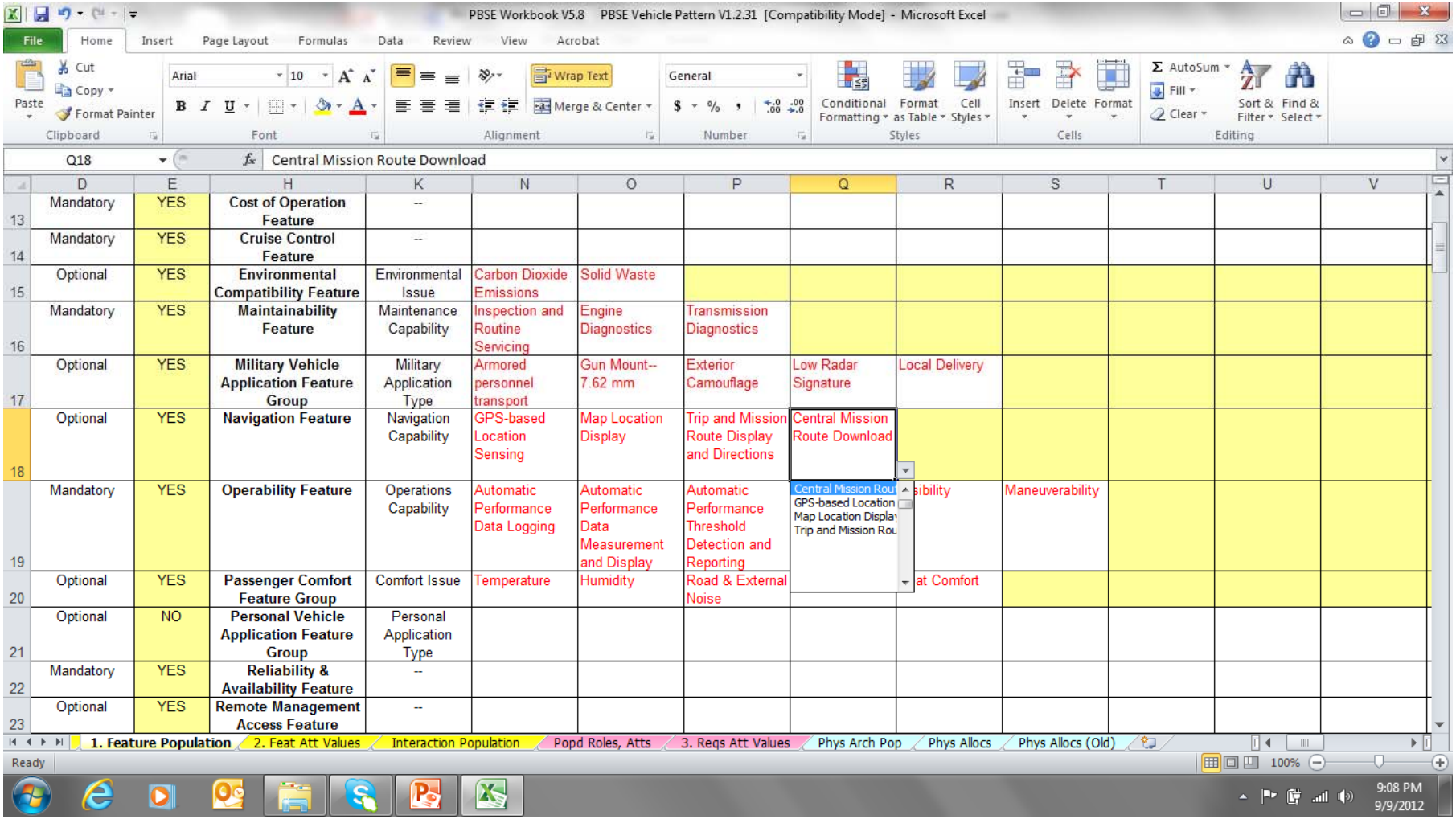


- The S*Pattern links Features to Requirements:
  - This means that populating a configuration of Features can automatically populate a configuration of Requirements--



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

Populating / depopulating Features:



	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						
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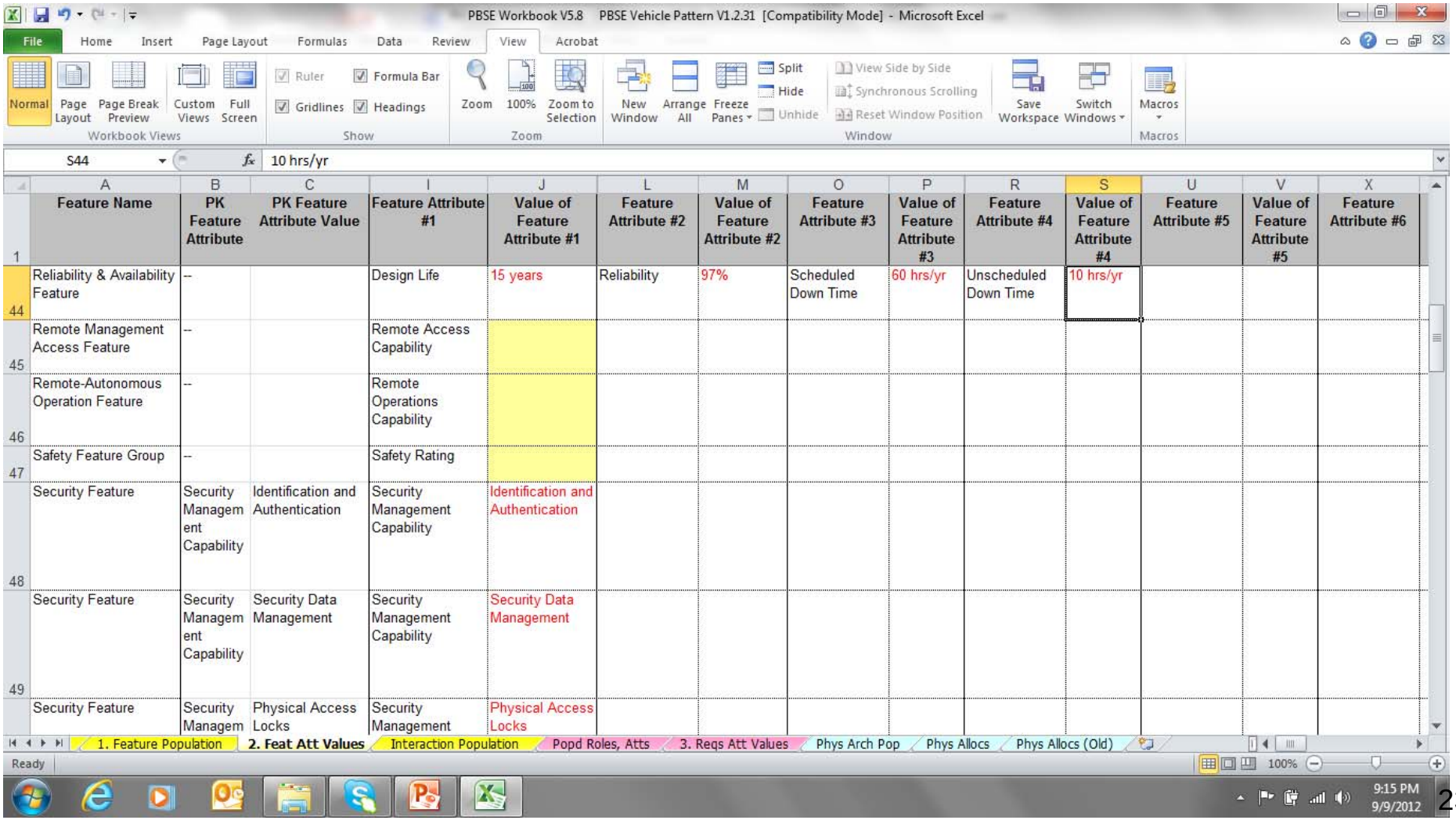
21	Optional	NO	**Personal Vehicle Application Feature Group**	Personal Application Type									
22	Mandatory	YES	**Reliability & Availability Feature**	--									
23	Optional	YES	**Remote Management Access Feature**	--									

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

Configuring Features: Setting Feature Attribute Values



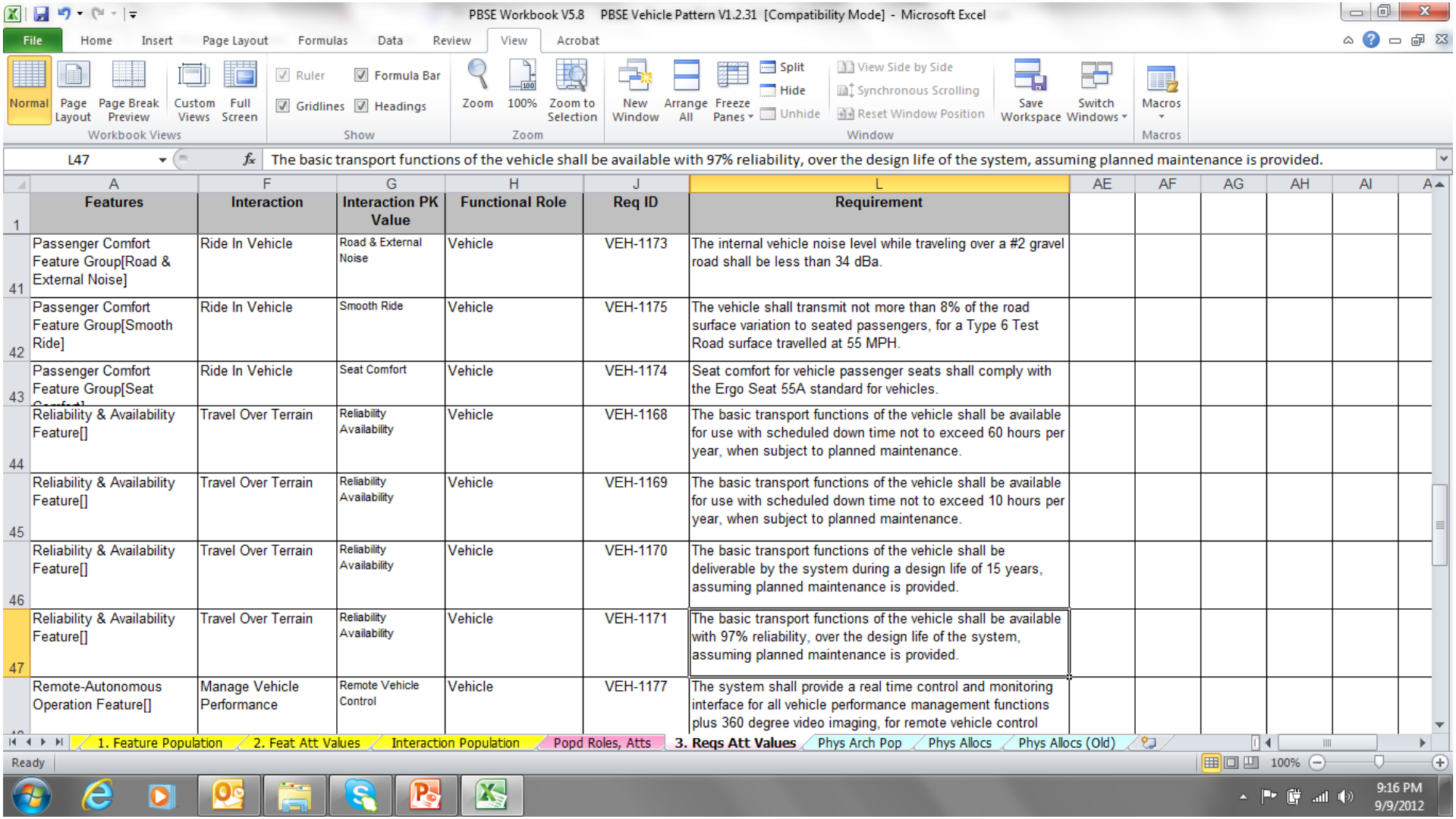
PBSE Workbook V5.8 PBSE Vehicle Pattern V1.2.31 [Compatibility Mode] - Microsoft Excel

S44: 10 hrs/yr

	A Feature Name	B PK Feature Attribute	C PK Feature Attribute Value	I Feature Attribute #1	J Value of Feature Attribute #1	L Feature Attribute #2	M Value of Feature Attribute #2	O Feature Attribute #3	P Value of Feature Attribute #3	R Feature Attribute #4	S Value of Feature Attribute #4	U Feature Attribute #5	V Value of Feature Attribute #5	X Feature Attribute #6
1														
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 Management Capability	Identification and Authentication	Security Management Capability	Identification and Authentication									
49	Security Feature	Security Management Capability	Security Data Management	Security Management Capability	Security Data Management									
	Security Feature	Security Managem	Physical Access Locks	Security Management	Physical Access Locks									

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

Ready



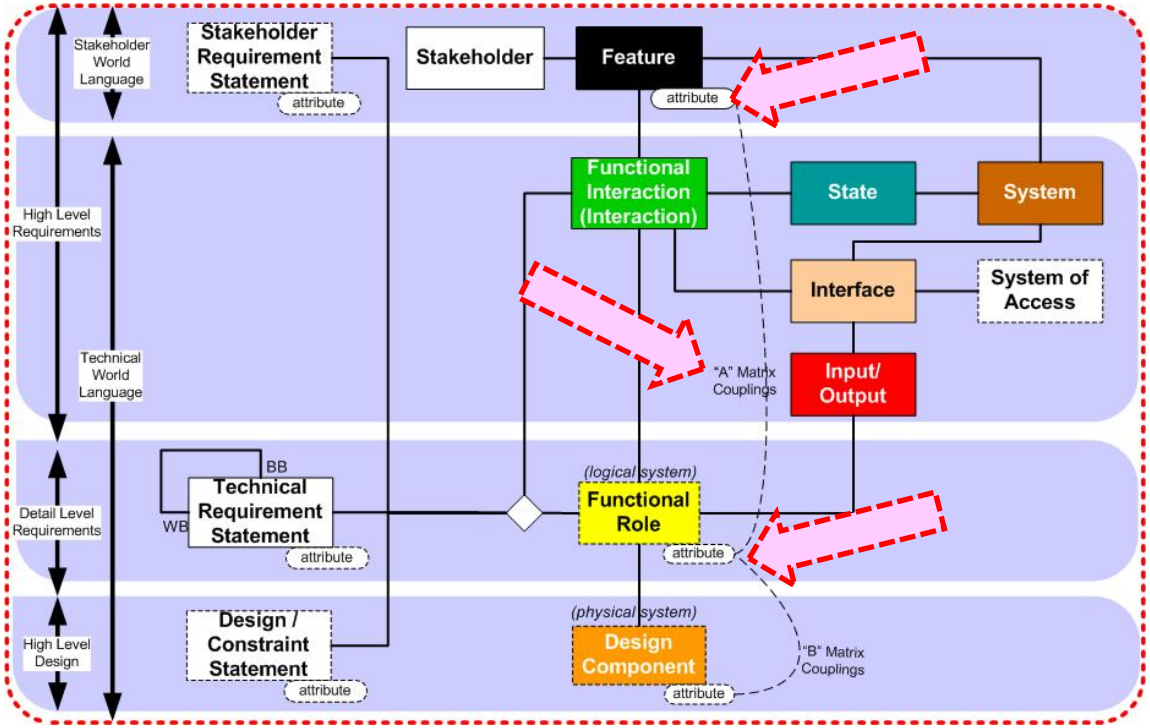
	A Features	F Interaction	G Interaction PK Value	H Functional Role	J Req ID	L Requirement
41	Passenger Comfort Feature Group[Road & External Noise]	Ride In Vehicle	Road & External Noise	Vehicle	VEH-1173	The internal vehicle noise level while traveling over a #2 gravel road shall be less than 34 dBa.
42	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	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

- Resulting Requirements:

  Attribute values can also be set, in line or in tables . . . .

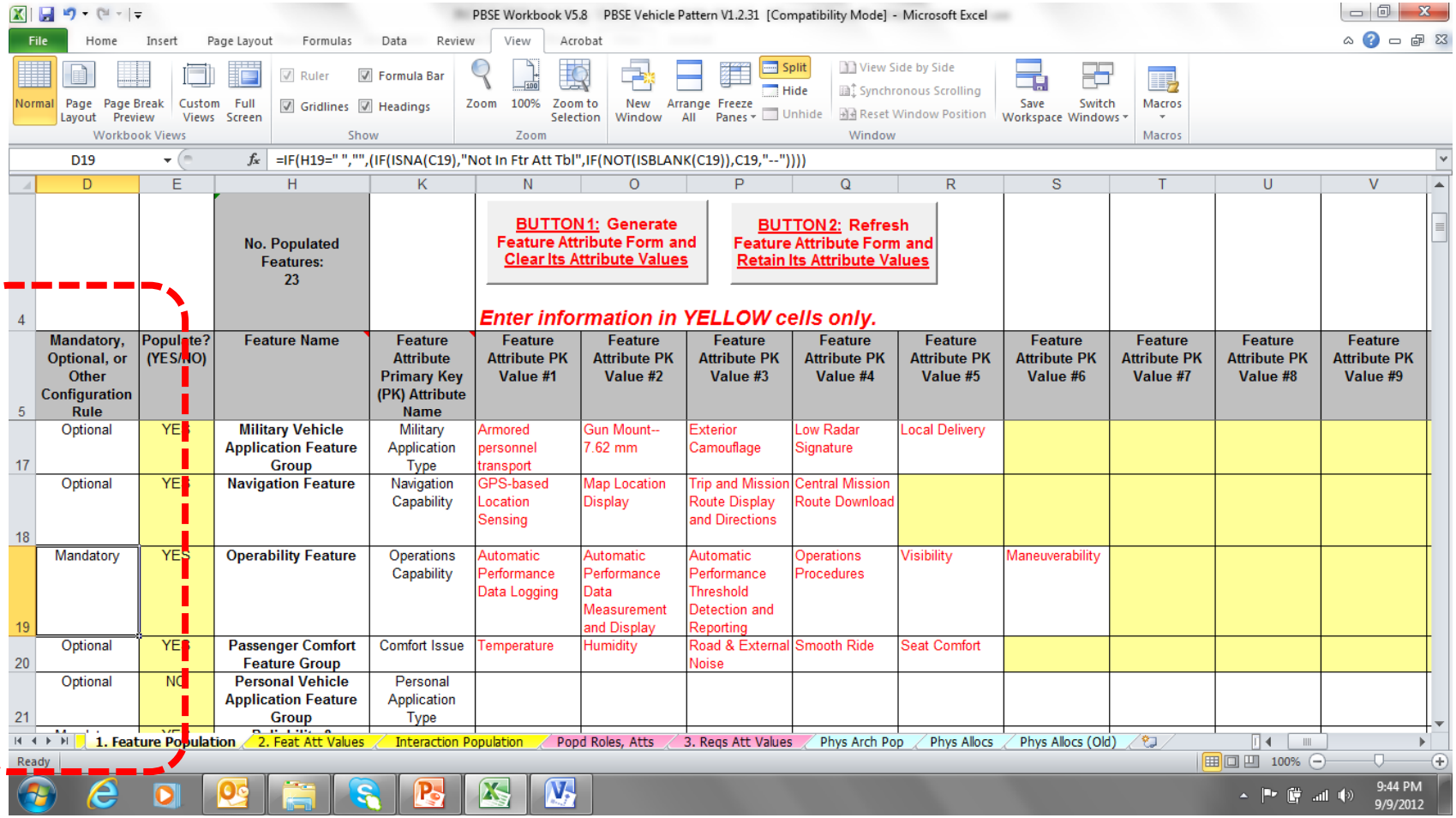
2. Using Pattern Configuration to generate better System Requirements faster: Example

- 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:



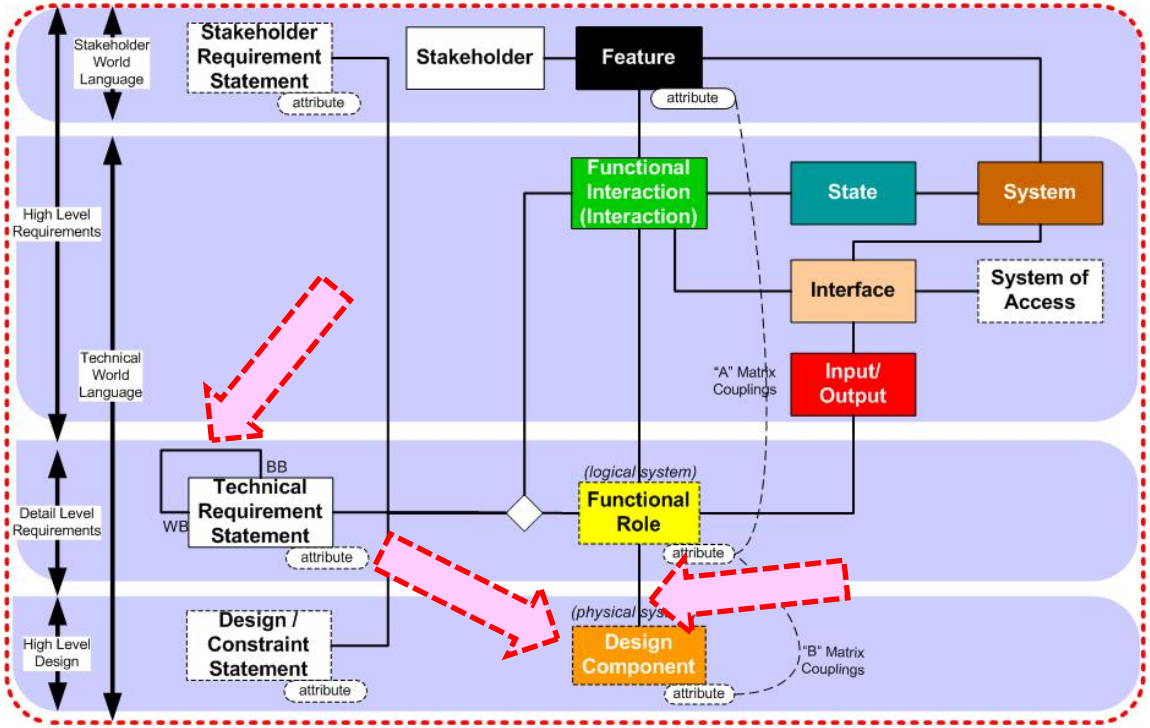
2. Using Pattern Configuration to generate better System Requirements faster: Example

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



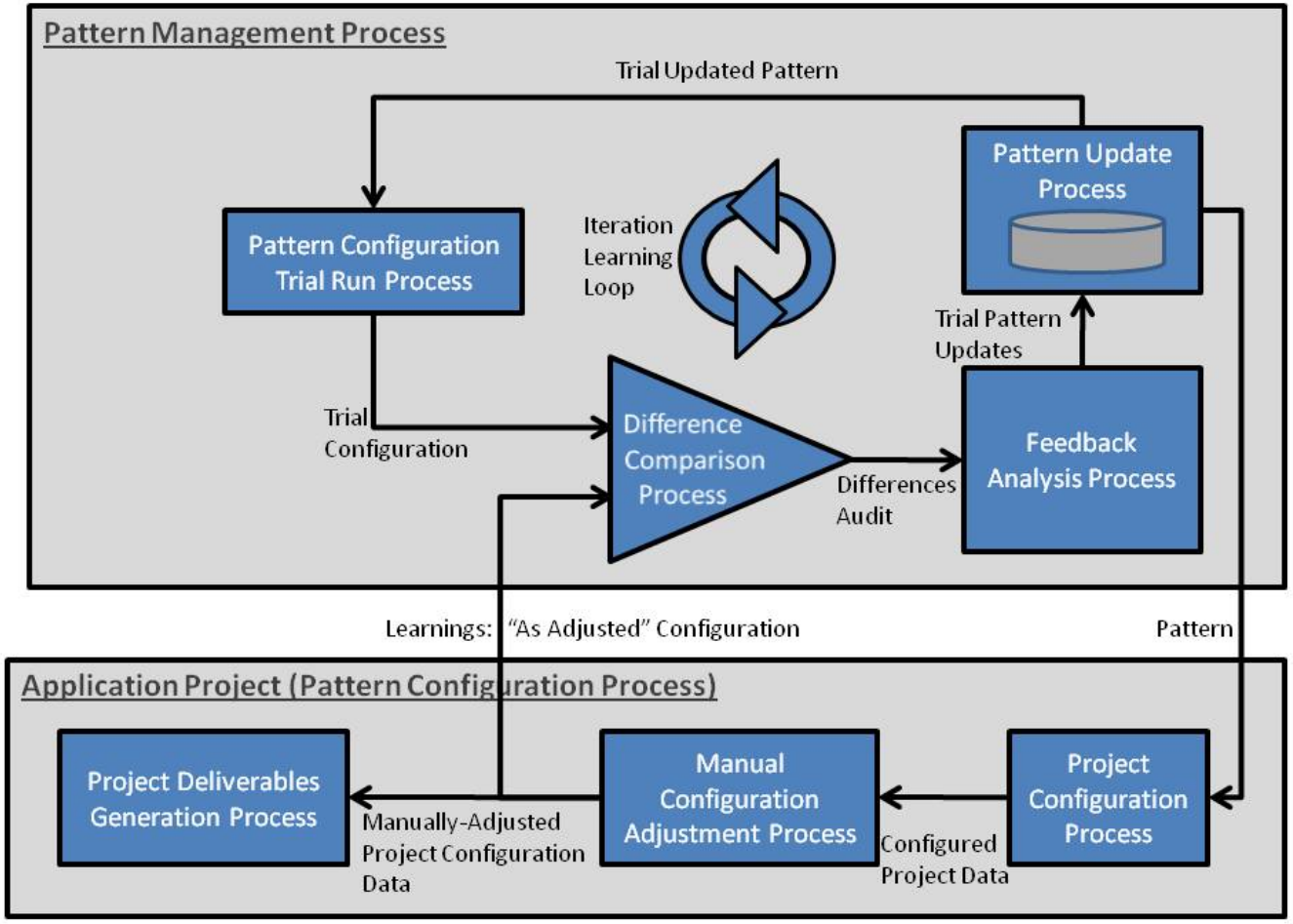
2. Using Pattern Configuration to generate better System Requirements faster

- The scope of a System Pattern can include more than Requirements:
  - Design Patterns include Physical Architecture, Requirements Decomposition, Requirements Allocations:



2. Using Pattern Configuration to generate better System Requirements faster

- PBSE processes continuously improve the content of the pattern, accumulating lessons for use in future projects:



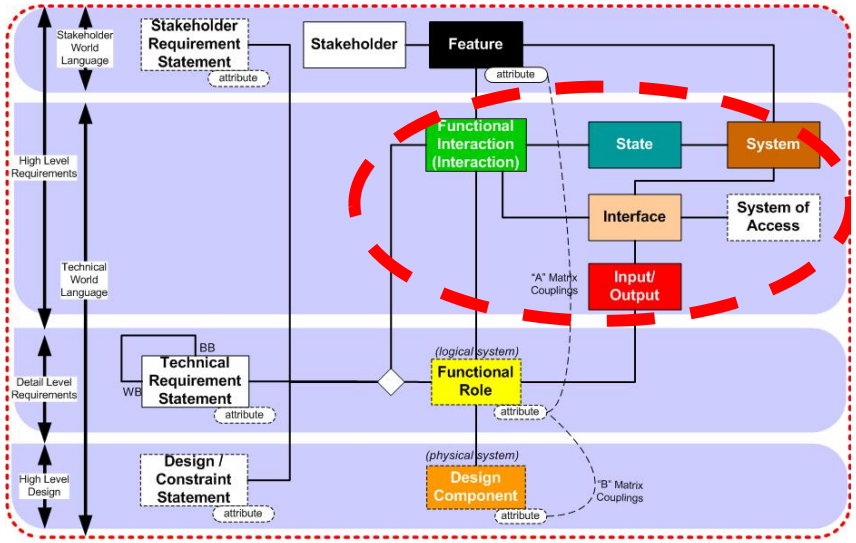
Historical / Back Up Materials:

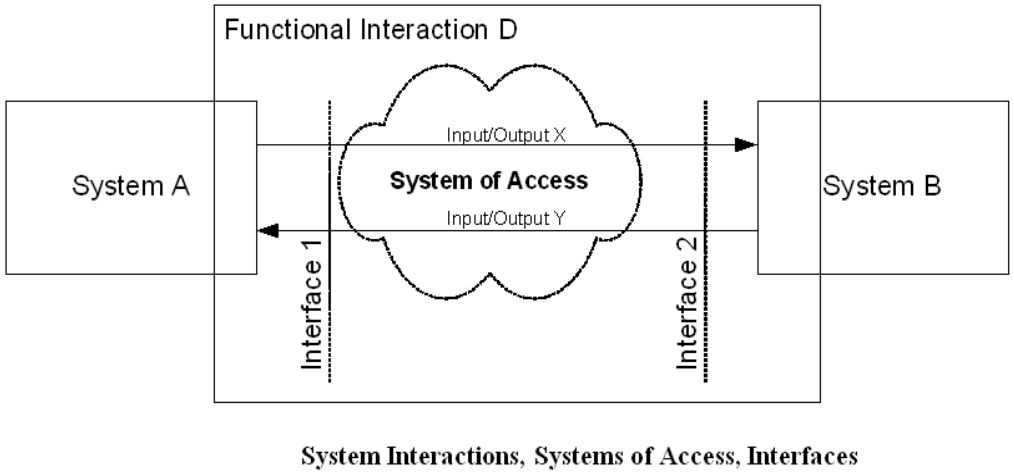
An example S*Pattern Extract

Lubricant (Oil) Filter Product Family

Walk-through of some initial S*Pattern segments

- **Functional Interaction**: Physical interactions, in which energy, force, mass, or information is exchanged between components. Can occur when the system is in a particular State.
- **Input-Output**: Energy, Force, Mass, or Information exchanged during Interactions.
- **Interface**: An association of a System (which has the interface), a set of Input-Outputs (which flow through the interface), a set of Interactions (which describe behavior at the interface), and a System of Access (which provides the external medium of interaction).
- **System of Access**: An external system providing an external medium of interactive exchange.
- **State**: Modes, Phases, Situations, having duration in time, during which some Interactions are eligible to occur and others are not.

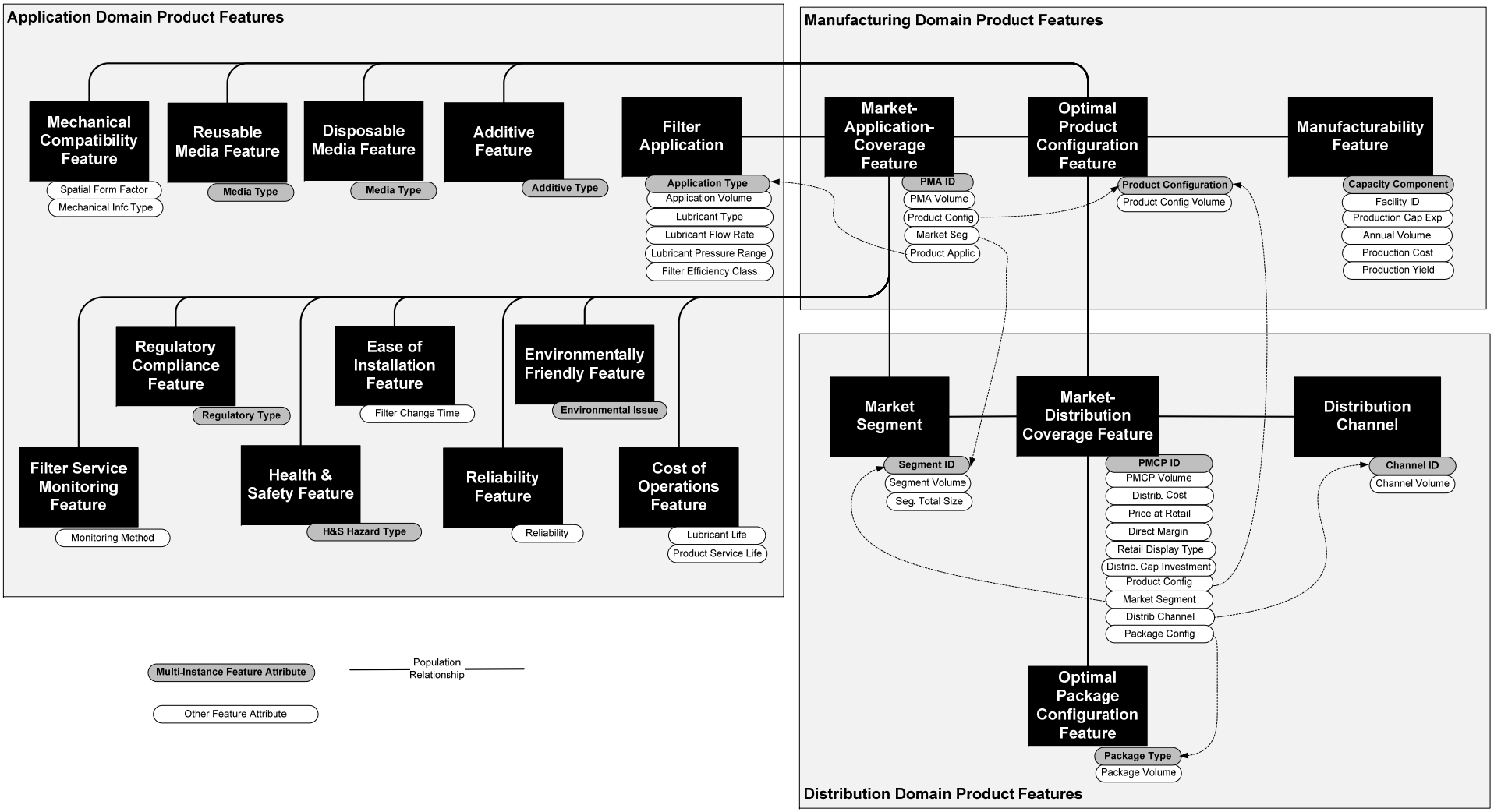




System Interactions, Systems of Access, Interfaces

Once we establish a Pattern for a Platform or Product Line System, specific configurations are generated by selection (population) of Features, and setting values for Feature Attributes.

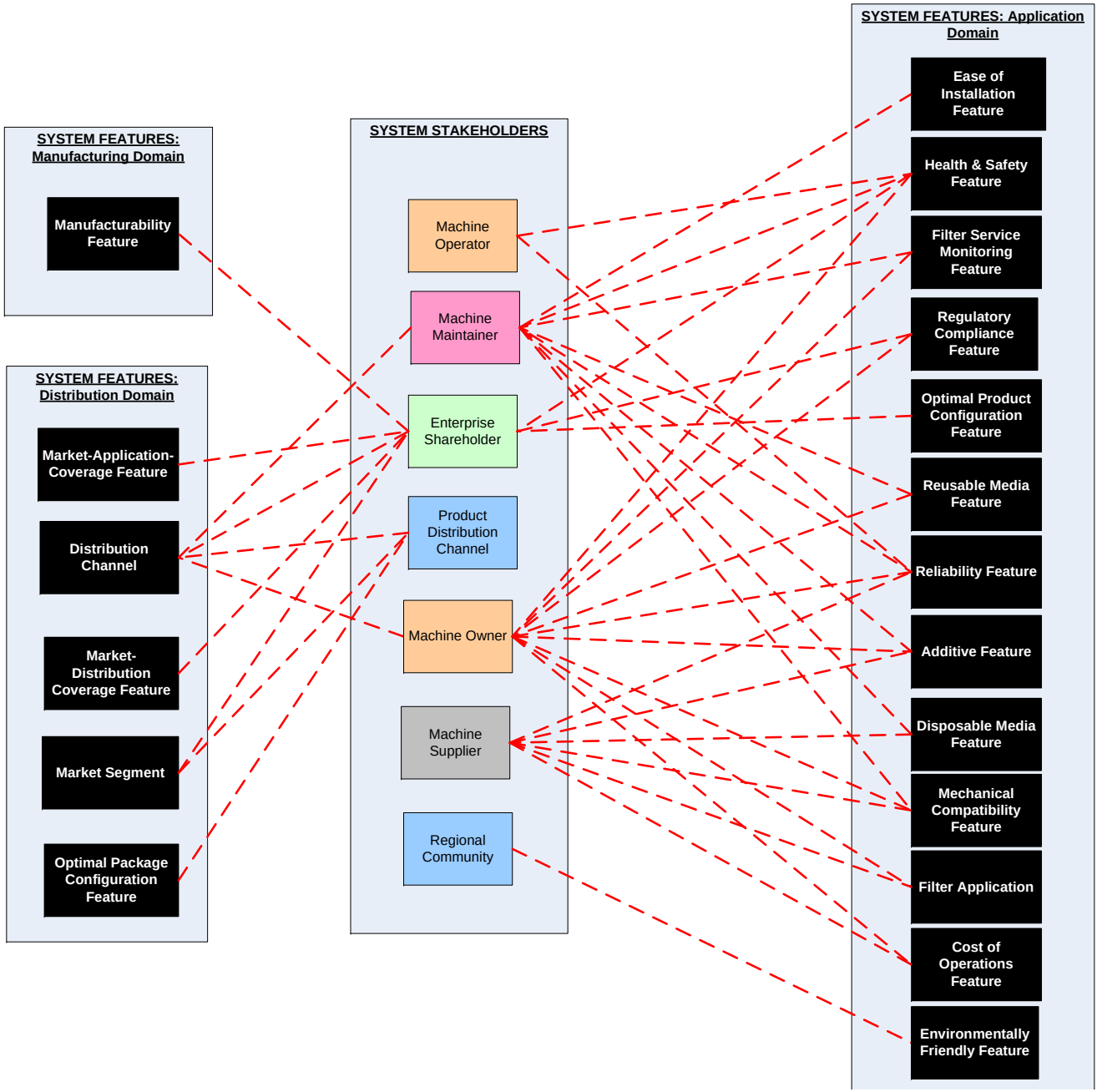
Example S*Pattern Stakeholder Feature Overview Model



Example S*Pattern Stakeholder Feature Model Extract

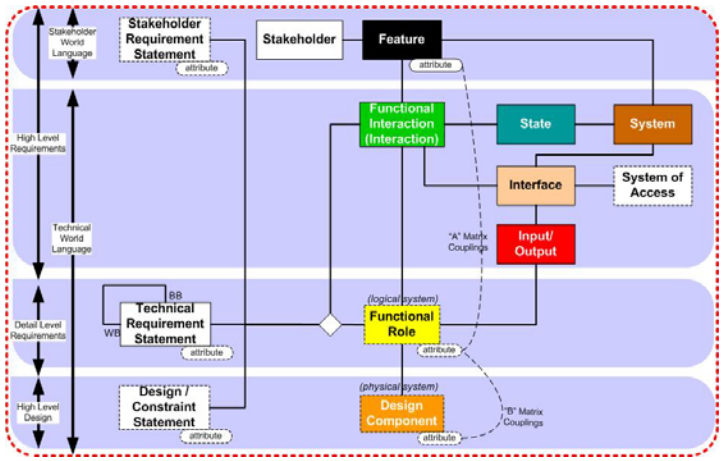
Feature	Feature Attribute	Multi-Instance	Attribute Definition	Attribute Units	Attribute Values
Optimal Product Configuration Feature	Product Configuration	X	Identifies the configuration of the product, as a model ID. Multiple configurations may be populated.	N/A	
Optimal Product Configuration Feature	Product Configuration Volume		The number of units of this product configuration produced per year.	Units/Year	
Filter Application	Application Type	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 Temperature Environment, Cold Environment
Filter Application	Application Volume		The number of units of this application placed into service during a year.	Units/Year	
Filter Application	Lubricant Type		The type of lubricating fluid to be used.	N/A	
Filter Application	Lubricant Flow Rate		The rate at which the lubricating fluid must be circulated in order to meet equipment lubrication objectives.	GPM	High, Medium, Low
Filter Application	Lubricant Pressure Range		The amount of hydraulic pressure under which the lubricant will circulate.	PSI	High, Medium, Low
Filter Application	Filter Efficiency Class		The profile of filtration efficiency provided by the filter	N/A	
Mechanical Compatibility Feature	Spatial Form Factor		The class of three dimensional structure of a component, subsystem, or space within a system reserved for a component or subsystem.	N/A	
Mechanical Compatibility Feature	Mechanical Interface Type		The mechanical class of the interface between the oil filter and the equipment to which it is connected.	N/A	
Cost of Operation Feature	Lubricant Life		The amount of time that a lubricant is intended to operate, meeting requirements within the specified environment, before it is replaced.	Hours	

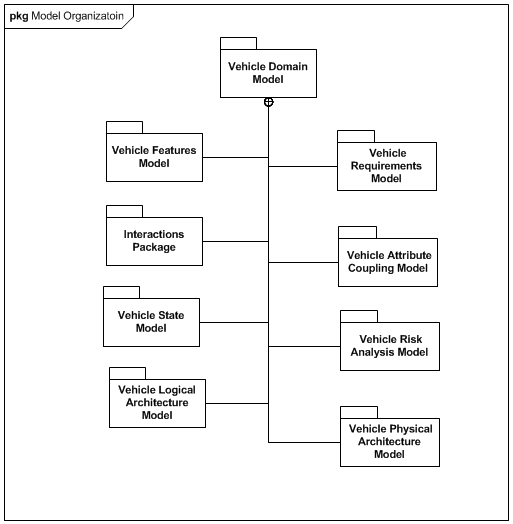
Example S*Pattern Stakeholder Feature Overview Model



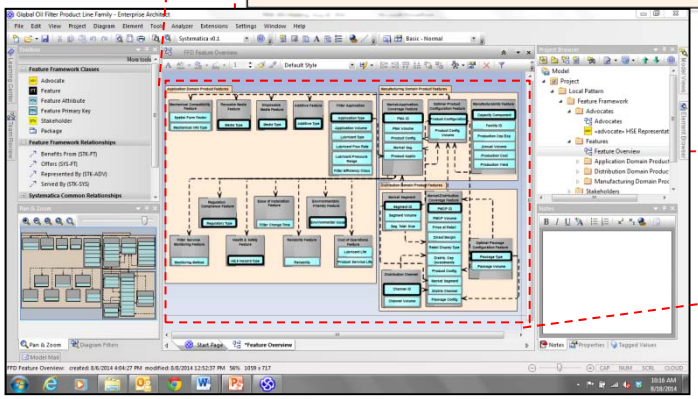
What modeling tools, languages will we use?

- S*Metamodel is modeling language independent:
  - Readily expressed in SysML or other modeling languages.
  - For INCOSE work, if the sub-team does not have a conflicting goal, we'd encourage use of SysML, familiar to more in INCOSE.
  - Be prepared to learn a few things that the modeling language standards have not quite caught up with yet.
  - One of our team's spin-offs is feedback to Sandy Friedenthal's inputs on future SysML releases.
  - If you have a different language in mind, we'll help.





Examples from Enterprise Architect (a SysML Modeling Tool)

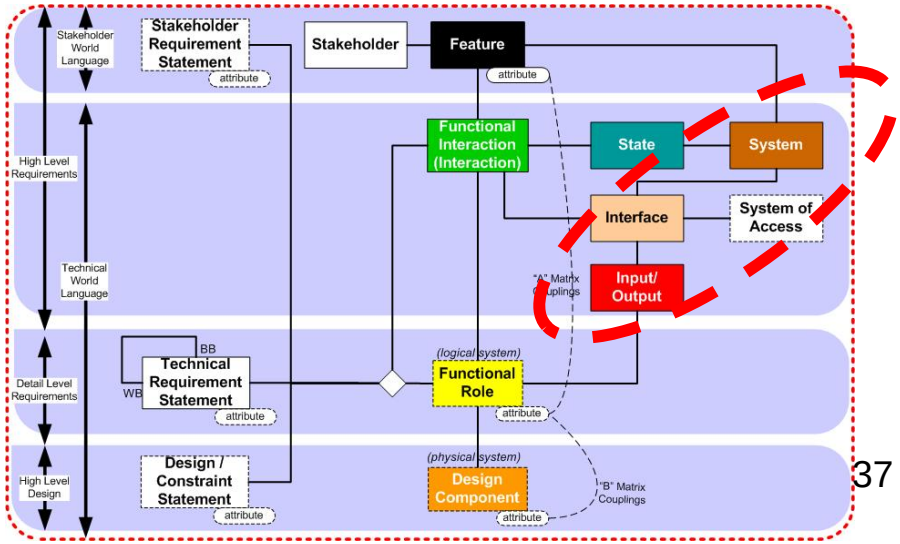


	Enterprise Shareholder	Machine Maintainer	Machine Operator	Machine Owner	Machine Supplier	Product Distribution Channel	Regional Community
Additive Feature		↑		↑	↑		
Cost of Operations Feature				↑			
Disposable Media Feature		↑		↑	↑		
Distribution Channel	↑	↑		↑		↑	
Ease of Installation Feature		↑					
Environmentally Friendly Feature							↑
Filter Application				↑	↑		
Filter Service Monitoring Feature		↑		↑			
Health & Safety Feature		↑	↑	↑			
Manufacturability Feature	↑						
Market-Application-Coverage Feature	↑						
Market-Distribution Coverage Feature	↑						
Market Segment	↑					↑	
Mechanical Compatibility Feature		↑		↑	↑		
Optimal Package Configuration Feature	↑					↑	
Optimal Product Configuration Feature	↑						
Regulatory Compliance Feature				↑			
Reliability Feature		↑	↑	↑	↑		
Reusable Media Feature		↑		↑			

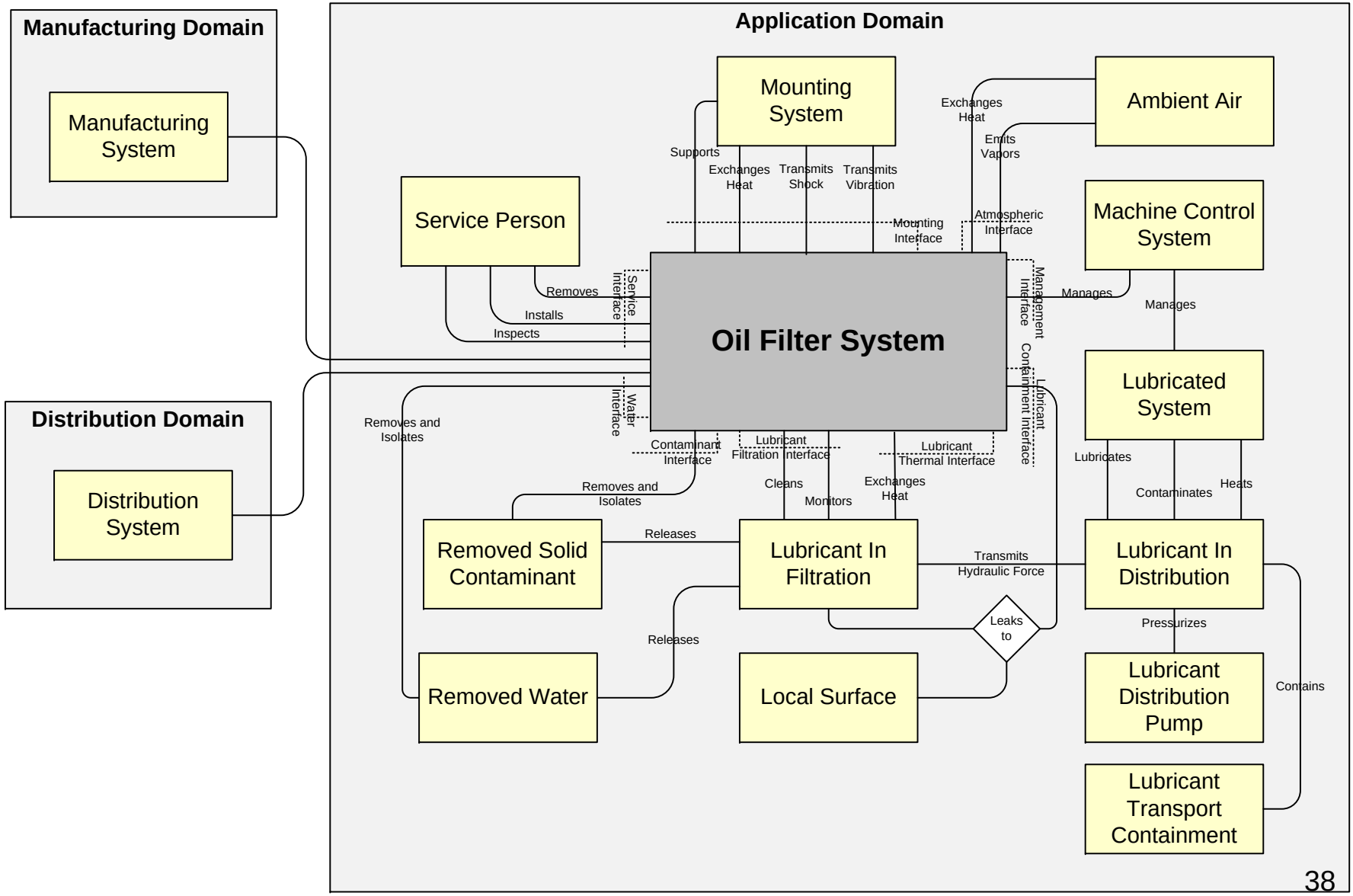
Examples from Enterprise Architect (SysML Modeling Tool)

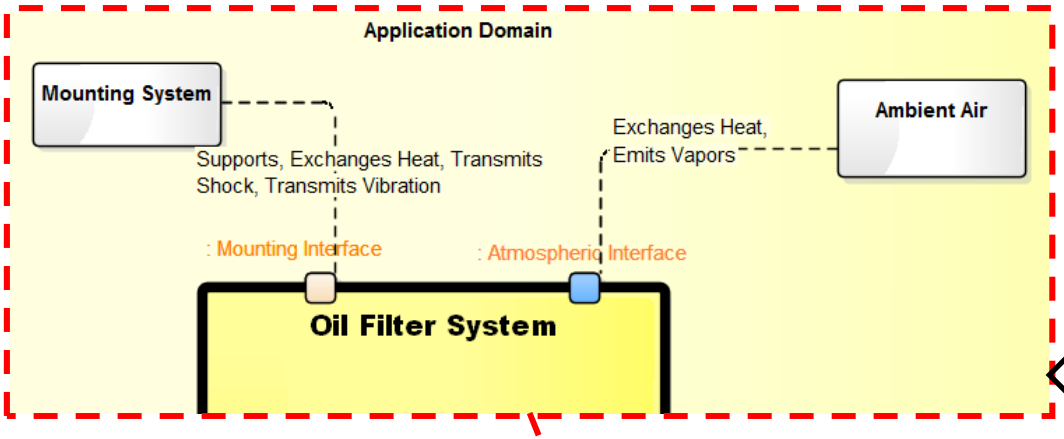
External “domain model” for System of Interest

- Will later help us identify all the external interactions with System of Interest.
  - **So what?** All system black box requirements are identified with (may be discovered through) those interactions.
- Domain diagram shows Actors, Interfaces, Input-Outputs or Relationship--:
  - **Actors**: People or other Systems that directly interact with the system of interest, by exchanges of force, energy, mass, or information.
  - **Input-Outputs**: The exchanged forces, energy, mass, or information.
  - **Domain Architecture Relationships**: Alternative way to summarize input-outputs
  - **Interfaces**: Associations of Systems (that “have” the interfaces), Input-Outputs (that “pass through” the interfaces), Interactions (that “describe behavior” at interfaces, and Systems of Access (that provide the external media of interaction).

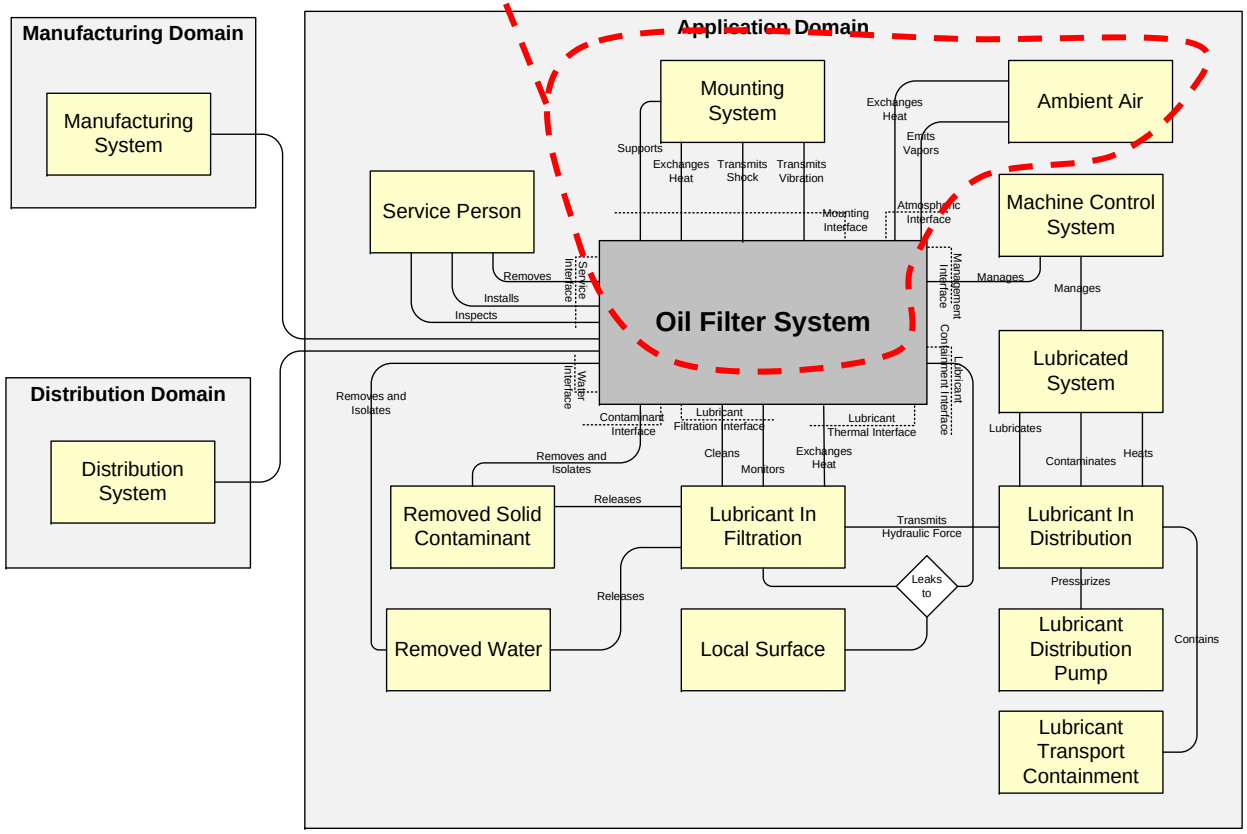


Domain model for Oil Filter System

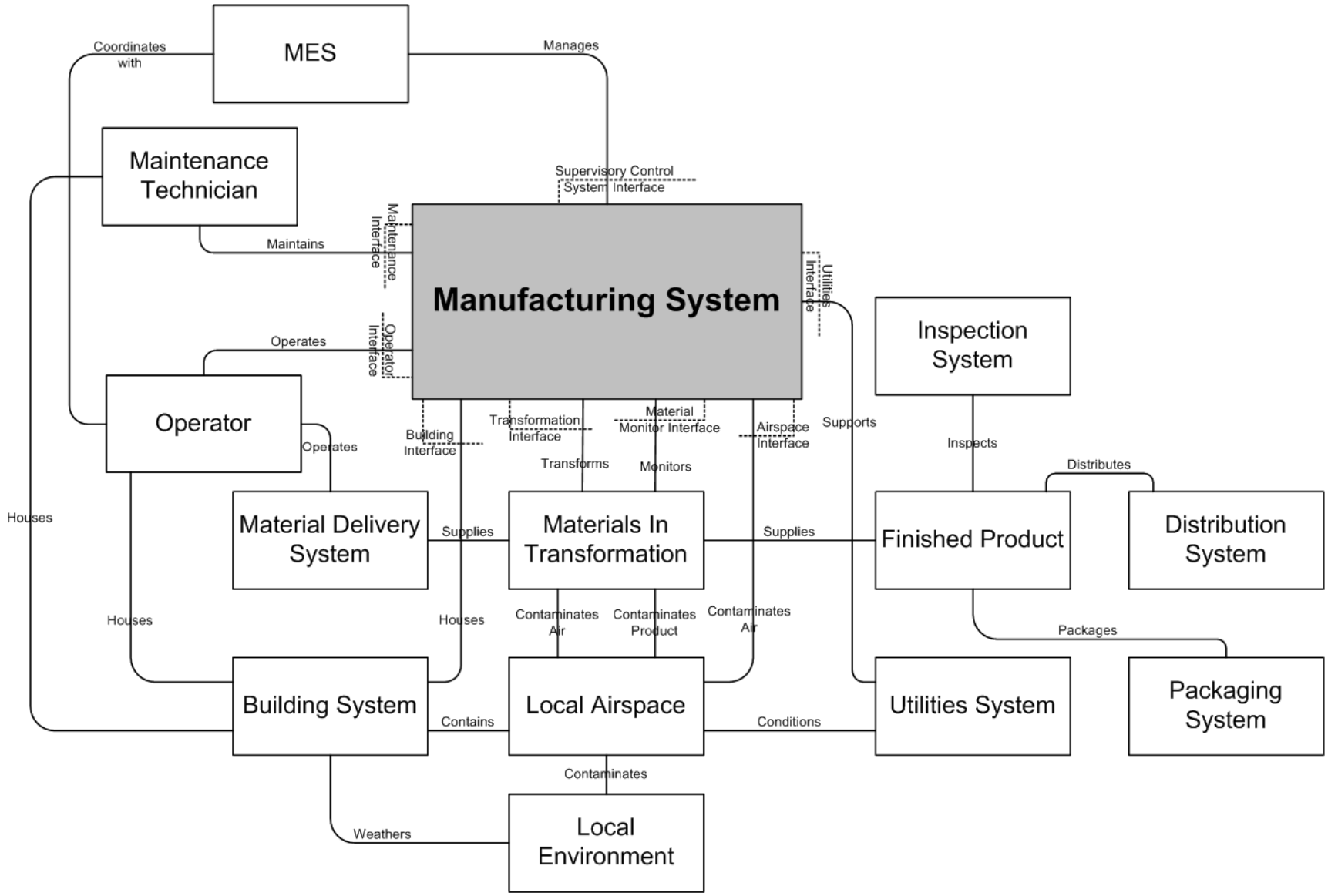




Extract from equivalent SysML Domain Model, in EA Tool



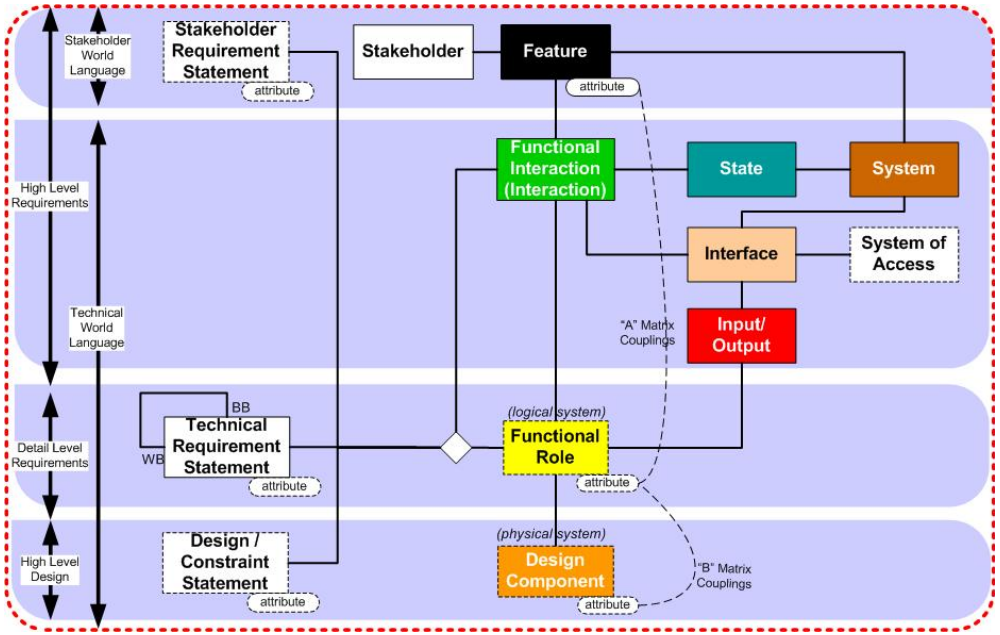
Domain model for Manufacturing System (of Oil Filter)



Patterns Demand Strongest Underlying Models

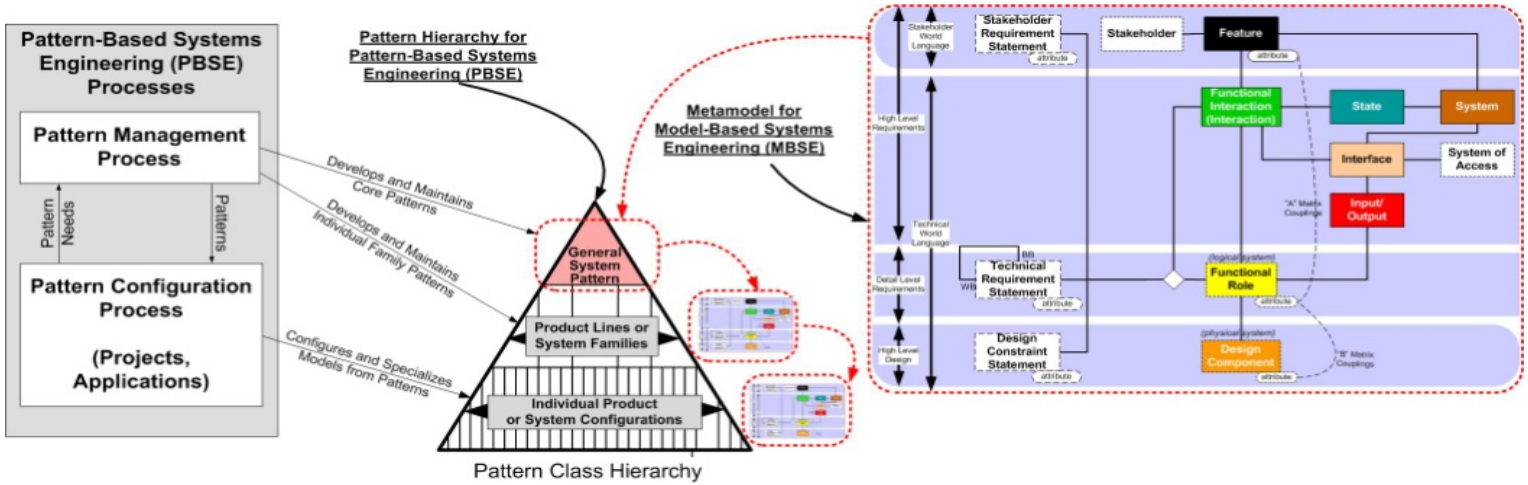
- The S*Metamodel describes the smallest set of ideas necessary to model a system for purposes of engineering or science:
  - Most of them familiar to modelers, and all of them basic to the training of engineers and scientists—*but not always found in their system models*.
  - A metamodel is a model of other models;
  - Sets forth underlying concepts of Requirements, Designs, Failures, Trade-offs, etc. (not modeling language syntax)

- The resulting S*Models may be expressed in SysML or other modeling languages, and constructed / reside in numerous commercial tools and information systems.
- Has been applied to SE in aerospace, transportation, medical, advanced manufacturing, communication, construction, consumer, other domains.



– The PBSE approach respects the systems engineering tradition, body of knowledge, and historical lessons, while providing a high-gain path forward.

– *An S* Pattern is a configurable, re-usable S* Model*. It is an extension of the idea of a Platform (which is a configurable, re-usable design). The Pattern includes not only the Platform, but all the extended system information (e.g., requirements, risk analysis, design trade-offs & alternatives, decision processes, etc.):



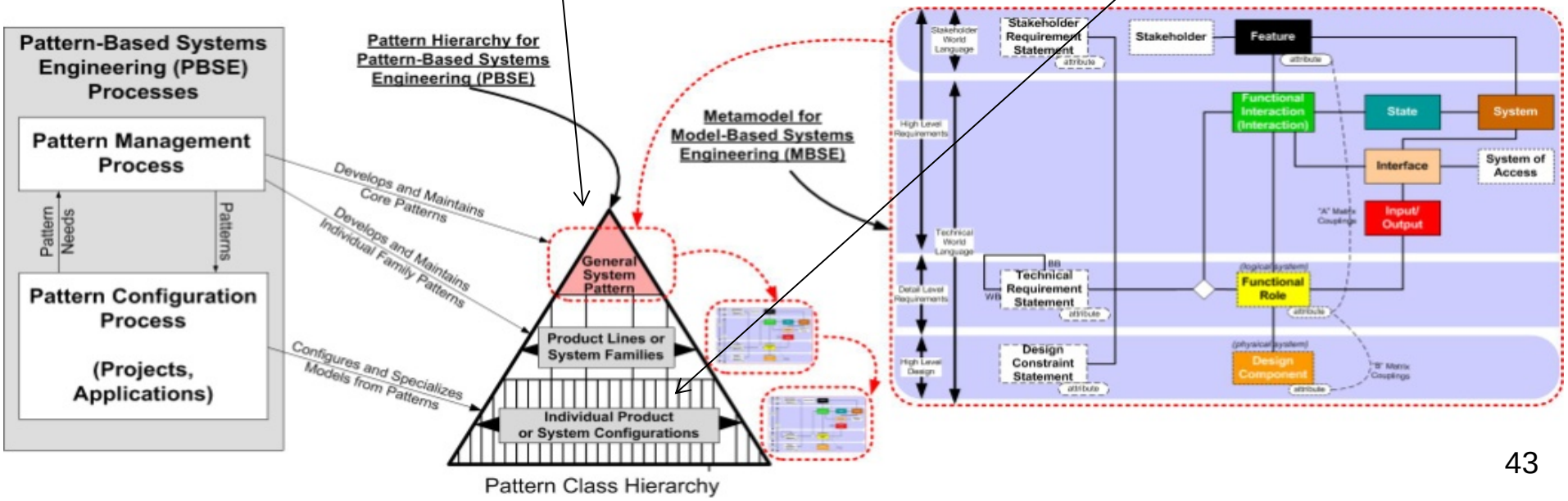
– By including the appropriate S* Metamodel concepts, these can readily be managed in (SysML or other) preferred modeling languages and tools—the ideas involved here are not specific to a modeling language or specific tool—ported to several.

– The order-of-magnitude changes have been realized because projects that use PBSE rapidly start from an existing Pattern, gaining the advantages of its content, and feed the pattern with what they learn, for future users.

– The “game changer” here is the shift from “learning to model” to “learning our (your) model”, freeing many people to rapidly configure, specialize, and apply patterns to deliver value in their model-based projects.

A little more about S*Patterns

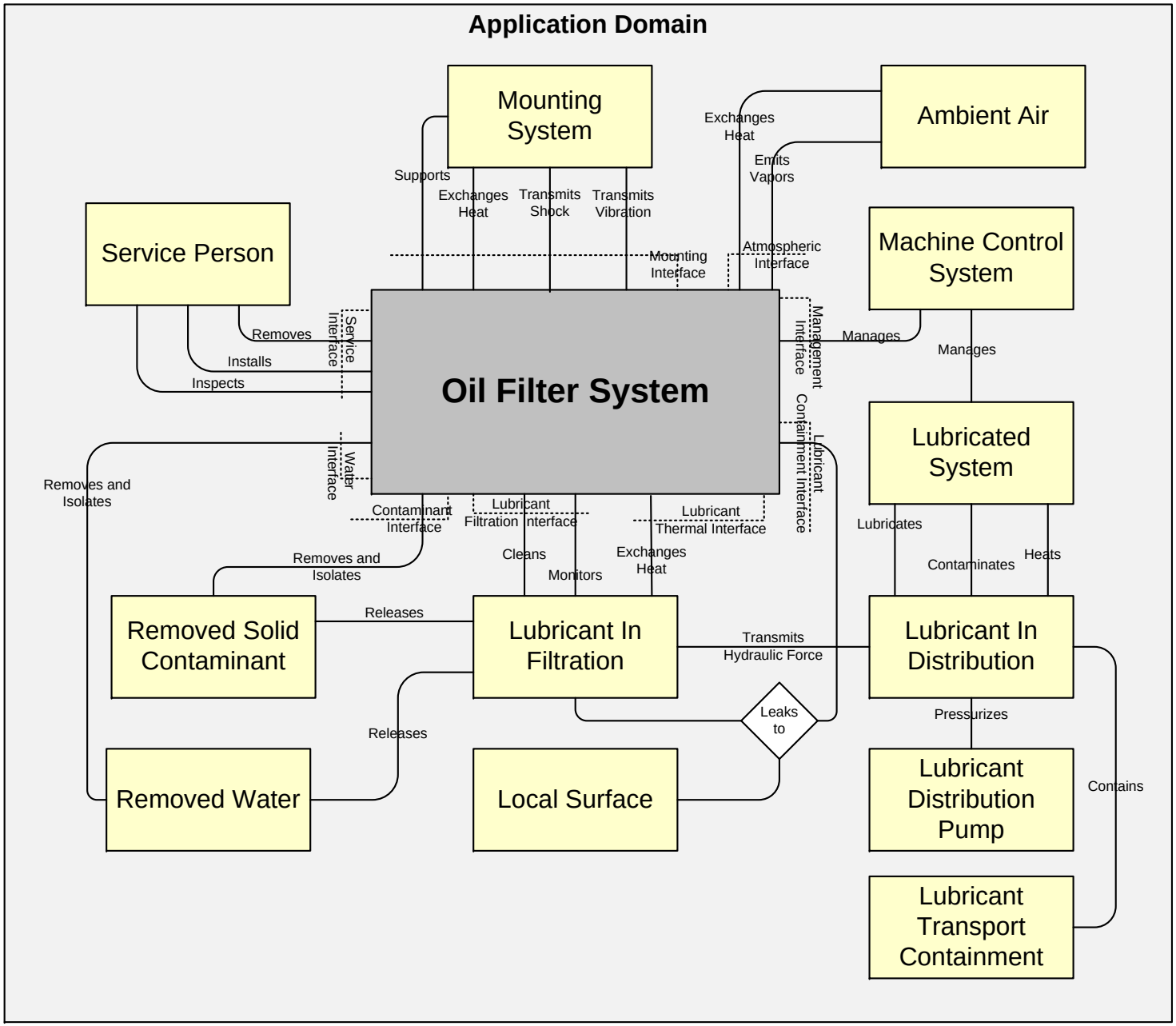
- Fixed (Pattern) Portion, Variable (Configuration) Portion, and the Configuration Process:
  - The generalized S*Pattern is expressed in exactly the same S*Metamodel classes and relationships as a specific configured S*Model derived from it.
  - "Configuring" a pattern means a process limited to exactly two things:
    - Populating (or de-populating) instances of classes and relationships
    - Setting the values of attributes (parameters)



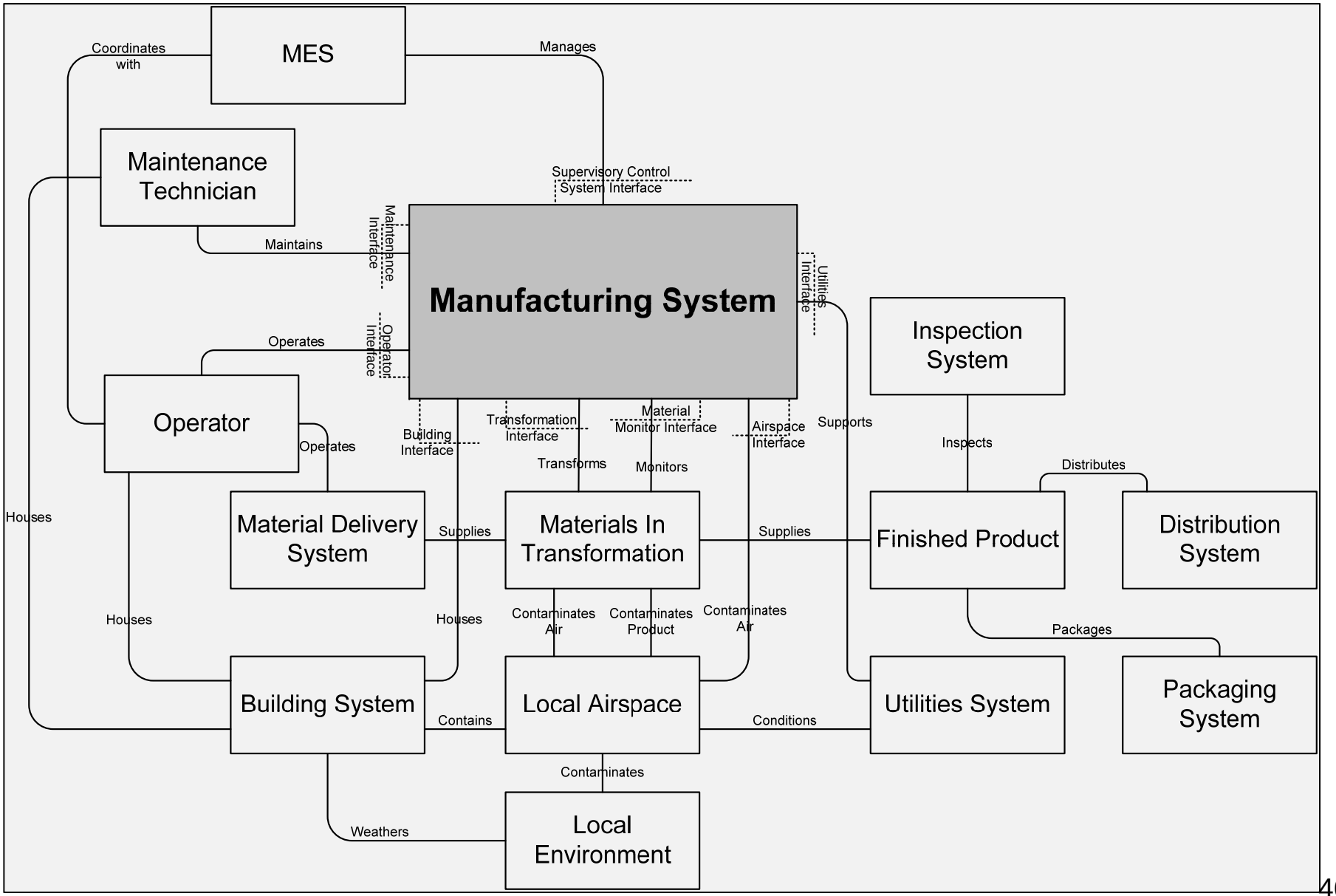
A little more about S*Patterns

- Having an S*Pattern meeting the underlying S*Metamodel demands has some surprising positive consequences beyond basic benefits of MBSE:
  - The Stakeholder Feature portion of the pattern directly generates a formal Trade Space / Scoreboard for arguing, defending all decisions.
  - "Configuring" the (low dimension) Stakeholder Feature portion of the Pattern for a specific project or system configuration can "automatically" generate the (high dimension) configured Technical Requirements for that system configuration.
  - For a sufficiently built-out S*Pattern, the same applies to the System Design (physical architecture, allocations, attribute couplings, etc.).
  - The S*Pattern can rapidly generate very complete first draft FMEA tables, since S*Features lead directly to modeled Effects, S*Requirements lead directly to modeled Counter-Requirements (functional failures), S*Design Components lead directly to modeled Failure Modes, and combinatorial FMEA analyses of the three together may be rapidly generated by machine matching algorithm.
- All these produce much faster initial drafts that are much more complete and consistent than manual approaches, but which can (should) still be subject to the normal human SME review and update:
  - We are not suggesting turning our thinking and fate over to the model, without human judgment, expertise, etc.

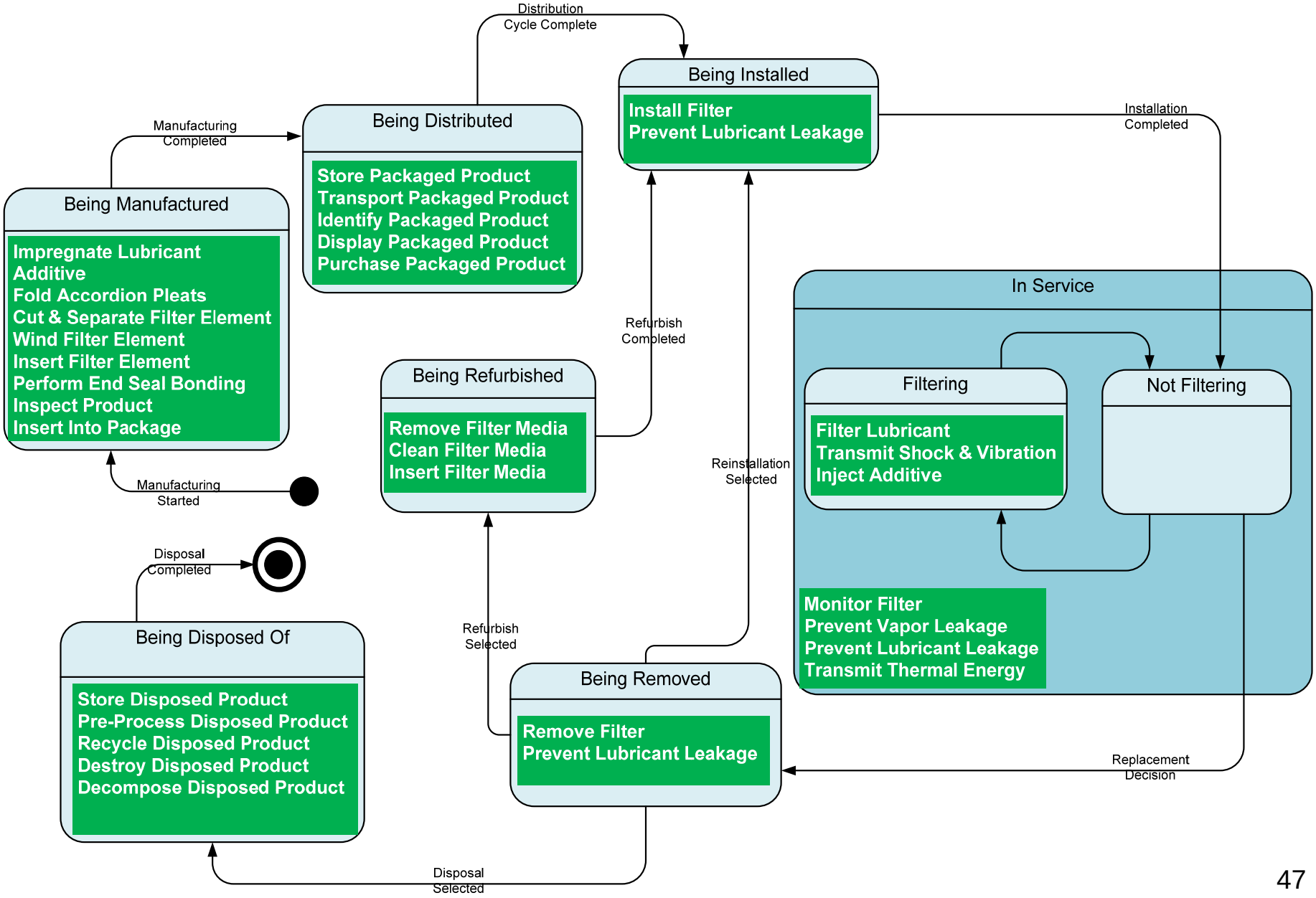
Example S*Pattern Application Domain Model



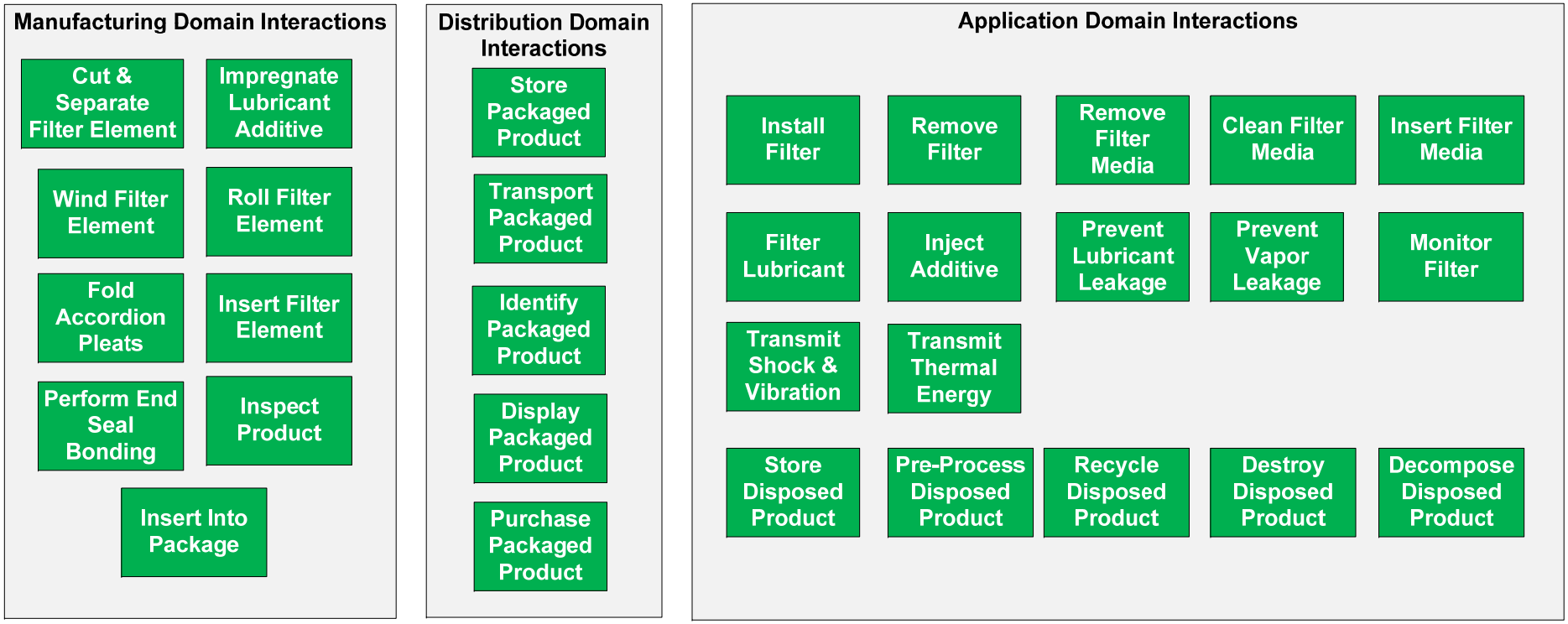
Example S*Pattern Manufacturing Domain Model



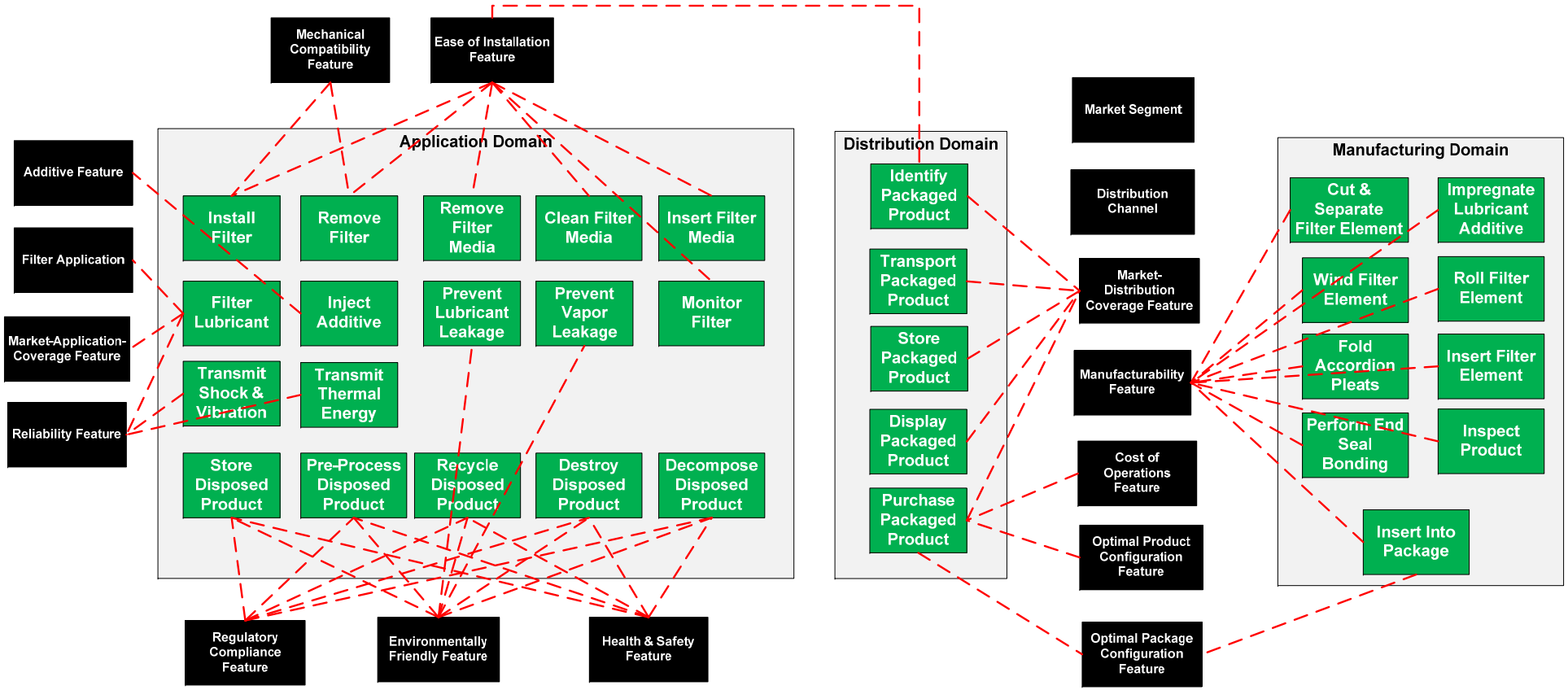
Example S*Pattern State (Modes) Model



Example S*Pattern Interaction Overview Model



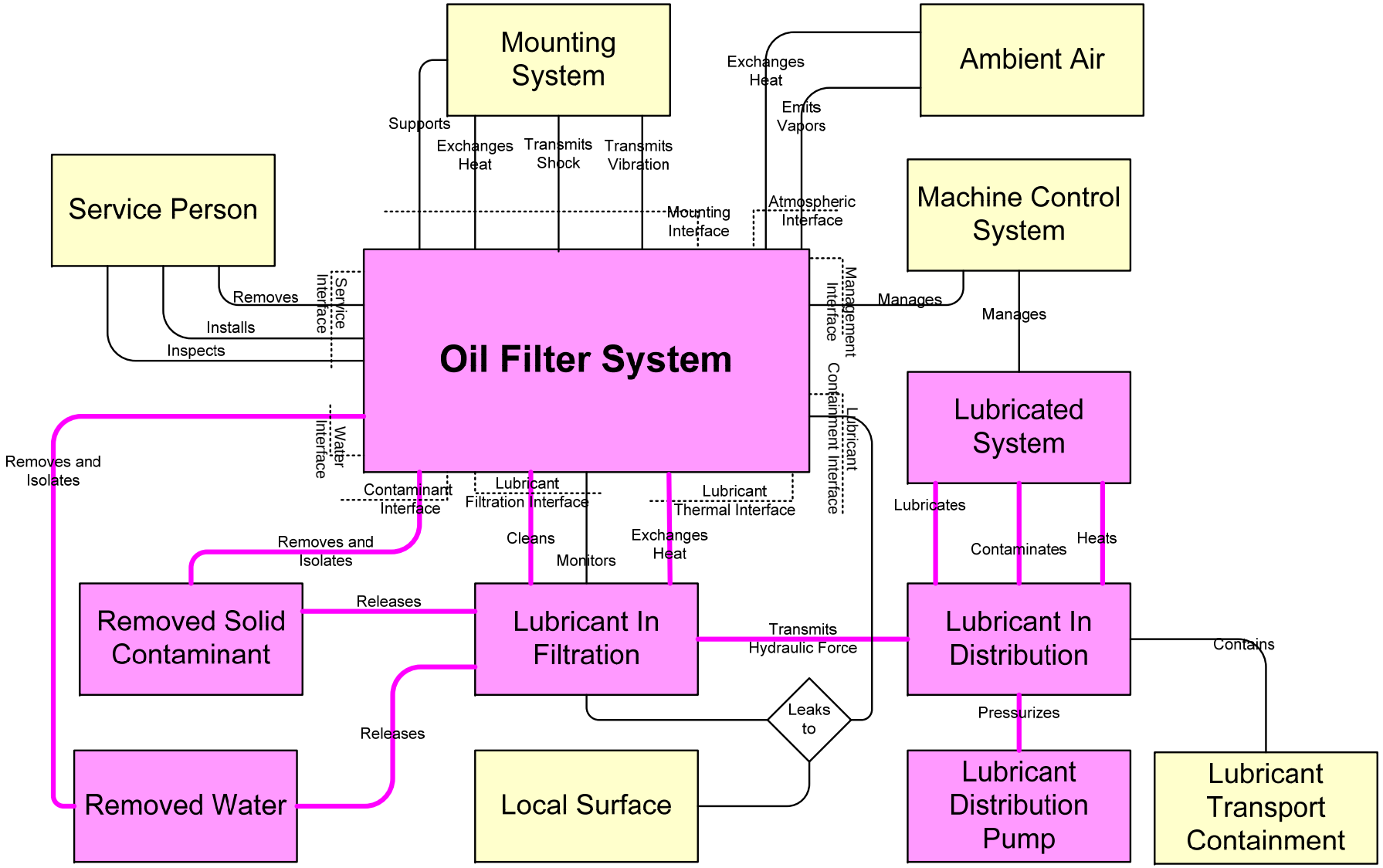
Example S*Pattern Feature-Interaction Associations Model (Part of Pattern Configuration Model)



Example S*Pattern Interaction Overview Model Extract

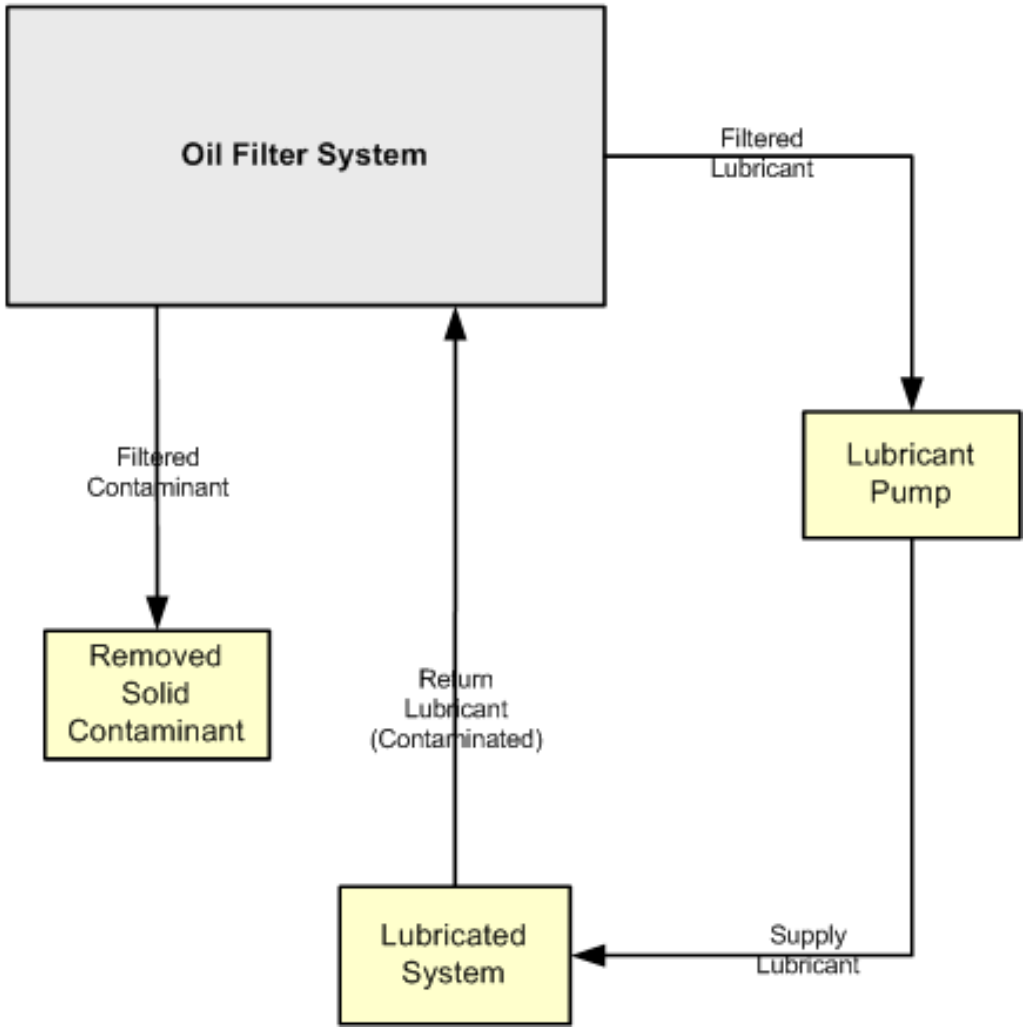
Interaction Name	Interaction Definition	Oil Filter System	Service Person	Mounting System	Ambient Air	Removed Solid Contaminant	Lubricant In Filtration	Removed Water	Local Surface	Lubricated System	Lubricant In Distribution	Lubricant Distribution Pump	Lubricant Transport Containment	Waste Management System	Manufacturing System	Distribution System	Package	Buyer
Filter Lubricant	The interaction during which the oil filter system filters the lubricant in filtration.	X		X		X	X	X		X	X	x	x					
Impregnate Lubricant Additive	The interaction during which the manufacturing system impregnates the oil filter with lubricant additive.	X													x			
Fold Accordion Pleats	The interaction during which the manufacturing system folds the sheet oil filter element into the form of accordion pleats.	X													x			
Cut & Separate Filter Element	The interaction during which the manufacturing system cuts and separates individual oil filter elements.	X													x			
Wind Filter Element	The interaction during which the manufacturing system winds the fiber oil filter element into a cylindrical shape.	X													x			
Insert Filter Element	The interaction during which the manufacturing system inserts the filter element into the filter housing.	X													x			
Perform End Seal Bonding	The interaction during which the manufacturing system bonds the end seal of the oil filter.	X													x			
Inspect Product	The interaction during which the manufacturing system inspects the finished oil filter product.	X													x			
Insert Into Package	The interaction during which the manufacturing system inserts the finished oil filter product into the package.	X													x	x	x	
Remove Filter Media	The interaction during which maintainer removes the filter media from the oil filter system.	X	X															
Clean Filter Media	The interaction during which the maintainer cleans the filter media.	X	X															
Insert Filter Media	The interaction during which the maintainer inserts the filter media back into the filter housing.	X	X															
Roll Filter Element	The interaction during which the manufacturing system rolls the sheet filter element into a cylindrical shape.	X													x			
Transmit Shock & Vibration	The interaction during which the oil filter system is subject to, and transmits, mechanical shock and vibration originating externally.	X		X														
Monitor Filter	The interaction through which the service person or lubricated equipment monitors the condition of the oil filter.	X	X															
Prevent Vapor Leakage	The interaction through which the oil filter prevents undue quantities of gaseous vapor contaminants from reaching the external local atmosphere.	X			X													
Prevent Lubricant Leakage	The interaction through which the oil filter prevents undue quantities of lubricant from escape from its portion of the lubrication loop.	X					X		X									
Transmit Thermal Energy	The interaction through which the oil filter receives and transmits thermal energy, originating in external components.	X		X	X		X											

Interaction: Filter Lubricant



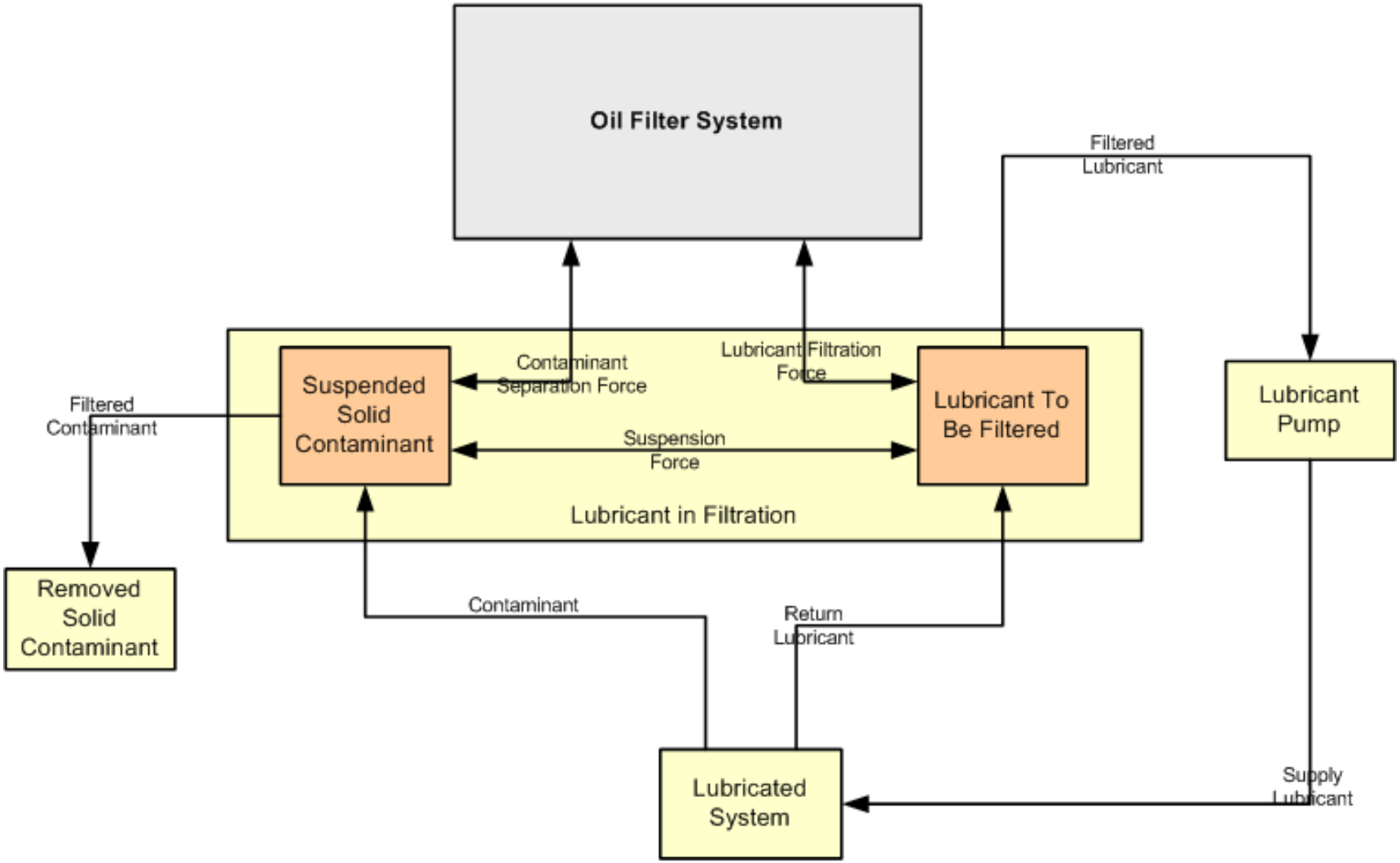
Detail Interaction Model Diagram Style 1:

Media Flow-Through, Other Actors Interacting with Subject System

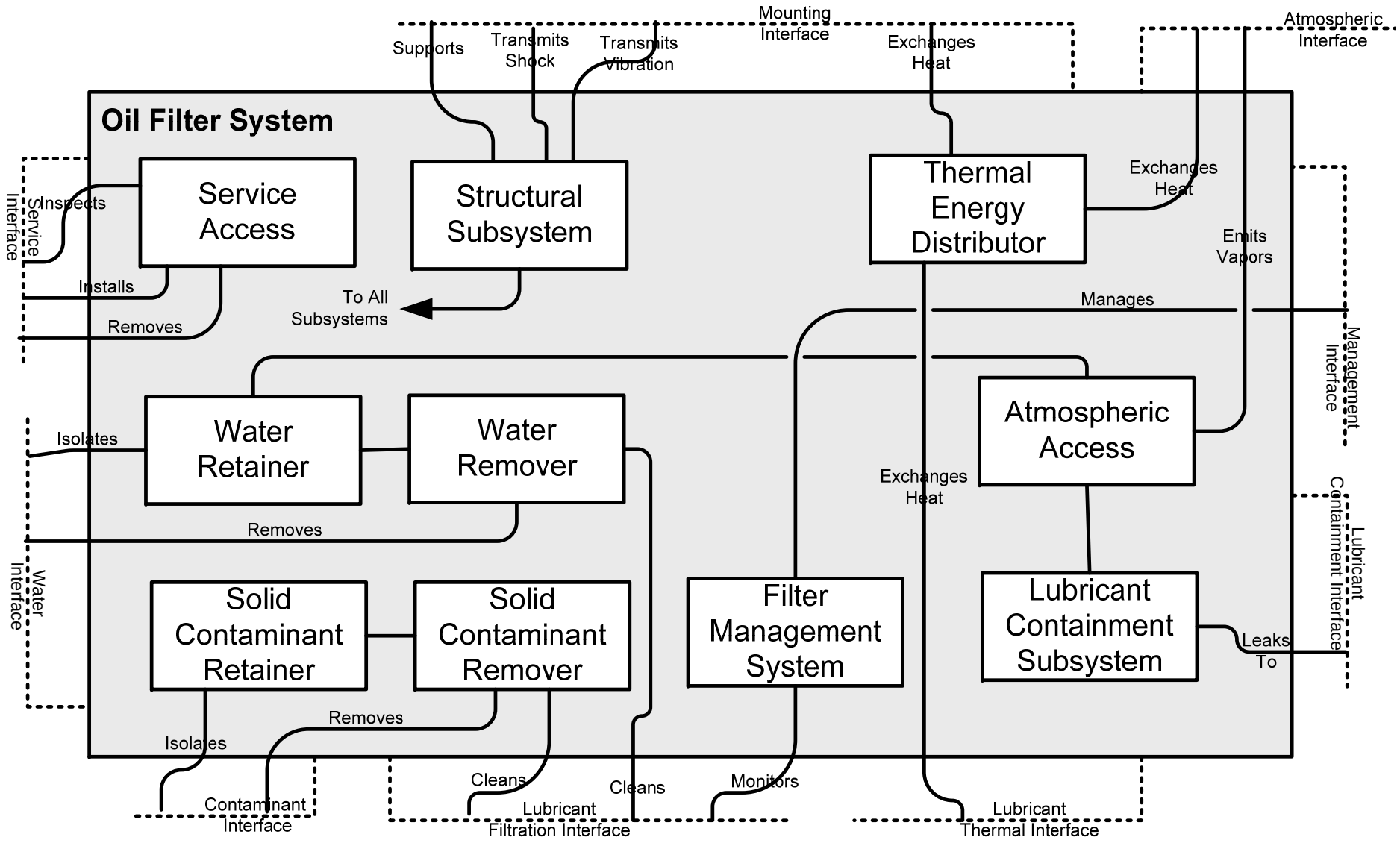


Detail Interaction Model Diagram Style 2:

Media Itself Interacting Externally with Subject System



Example S*Pattern Logical Architecture Model



Example S*Pattern Requirements Model -- Extract

Interaction	Role	ID	Requirement Statement
Filter Lubricant	Oil Filter System	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].
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].
Filter Lubricant	Oil Filter System	OF-52	The Oil Filter shall accommodate a Lubricant flow rate of [Lubricant Flow Rate].
Filter Lubricant	Lubricant Distribution Pump	OF-53	The Pump shall maintain oil pressure within the [Lubricant Pressure Range].
Filter Lubricant	Lubricant In Filtration	OF-54	The Lubricant in Filtration shall have viscosity within the [Lubricant Viscosity Range].
Filter Lubricant	Lubricated Machine	OF-55	The Lubricated Machine shall contribute a Contaminant Load to the lubricant, not to exceed [Lubricant Contaminant Load Rate].
Filter Lubricant	Lubricated Machine	OF-56	The Lubricated Machine shall not heat the lubricant above [Max Lubricant Temperature].
Inject Additive	Oil Filter System	OF-57	The Oil Filter shall inject additive of type [Additive Type] into the Lubricant flow, at a rate of [Additive Injection Rate] per unit of lubricant flow, over the service life of the filter element.
Remove Filter Media	Oil Filter System	OF-90	The Oil Filter System shall permit the removal of its used Filter Media.
Remove Filter Media	Oil Filter System	OF-91	The Oil Filter System filter media removal process shall allow the service person to avoid direct contact contamination with filtered contaminants and lubricant.
Clean Filter Media	Oil Filter System	OF-92	The Oil Filter System shall permit the cleaning of its used Filter Media, for reuse purposes, using cleaning solvent and method of type [Filter Media Cleaning Method and Solvent].
Clean Filter Media	Oil Filter System	OF-93	The Oil Filter System filter cleaning process shall allow the service person to avoid direct contact contamination with filtered contaminants and lubricant.
Insert Filter Media	Oil Filter System	OF-94	The Oil Filter System shall permit the insertion of its Filter Media, of type [Filter Media Type].
Insert Filter Media	Oil Filter System	OF-95	The Oil Filter System filter media insertion process shall allow the service person to avoid direct contact contamination with filtered contaminants and lubricant.
Transmit Shock & Vibration	Oil Filter System	OF-100	The system shall meet its other requirements when subject to a vibration spectrum not exceeding [Max Vibration Spectrum] during its in-service life.
Transmit Shock & Vibration	Oil Filter System	OF-101	The system shall meet its other requirements when subject to shock intensity and frequency not exceeding [Max Shock Intensity and Frequency] during its in-service life.
Monitor Filter	Oil Filter System	OF-102	The system shall provide a means of inspection of its remaining service life before requiring servicing, using [Filter Monitoring Method].
Prevent Vapor Leakage	Oil Filter System	OF-103	When operating within its rated lubricant pressure and temperature, at altitudes not exceeding [Max Service Altitude], the system shall maintain Vapor Leakage to the ambient air space below [Max Vapor Leakage Rate].
Prevent Lubricant Leakage	Oil Filter System	OF-104	When operating within its rated lubricant pressure and temperature, at altitudes not exceeding [Max Service Altitude], the system shall maintain Fluid Leakage to the surrounding space below [Max Fluid Leakage Rate].
Transmit Thermal Energy	Oil Filter System	OF-105	The system shall meet its other requirements while operating in external ambient air temperatures of [External Temperature Range] and lubricant temperatures of [Lubricant Temperature Range].
Install Filter	Oil Filter System	OF-106	The Oil Filter shall be manually installable in ten minutes or less, using only a screwdriver.
Install Filter	Oil Filter System	OF-107	The Oil Filter shall have installation instructions printed on its exterior surface, in [National Language] language.
Install Filter	Oil Filter System	OF-110	The Oil Filter shall not present sharp edge hazards to the installer during the installation process.
Install Filter	Oil Filter System	OF-111	The Oil Filter shall be clearly labeled with instructions to shut down pressurized equipment prior to installation.
Install Filter	Service Person	OF-112	The Service Person with the visual acuity and hand strength of an average 40 year old adult shall be able to install the Oil Filter System.
Install Filter	Service Person	OF-113	The Service Person shall be capable of reading [National Language] at the tenth grade level.

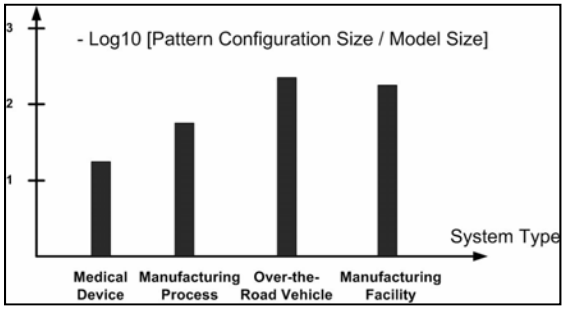
Pattern Configurations

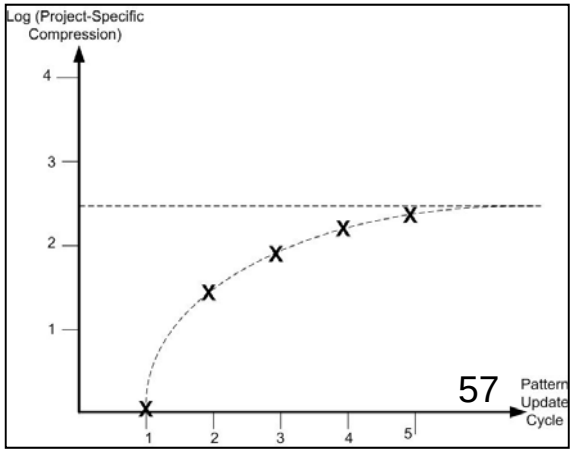
Product/Feature	Ice Road Trucking	Consumer Auto	Commercial Auto	Fixed Based Engine
Engine Lubricant Filtration Feature	Cold Environment	Consumer Automotive	Commercial Automotive	Fixed Based Engine System
Mechanical Compatibility Feature	X	X	X	X
Cost of Operation Feature	X	X	X	X
Reliability Feature	X	X	X	X
Maintainability Feature	X	X	X	X
Additive Feature	No. 7 Efficiency Boost	No. 5 Life Extension	No. 6 Efficiency Boost	No. 3 Efficiency Boost
Environmentally Friendly Feature	X	X	X	X

Pattern Configurations, Model Compression

- 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 Push Mower	Walk-Behind Mower	Walk-Behind Self-Propelled	Riding Rider	Riding Tractor	Riding Mower Tractor	Autonomous 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	





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