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Frenemies: OPM and SysML Together in an MBSE Model

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- July, 2019

Agenda

- Introduction
- OPM
- OPM and SysML together
- ISO 15288 & MBSE
- Conclusions
- Questions and Answers?

Platforms/Divisions

Agriculture

Lawn & Garden

Construction

Landscaping &
Grounds Care

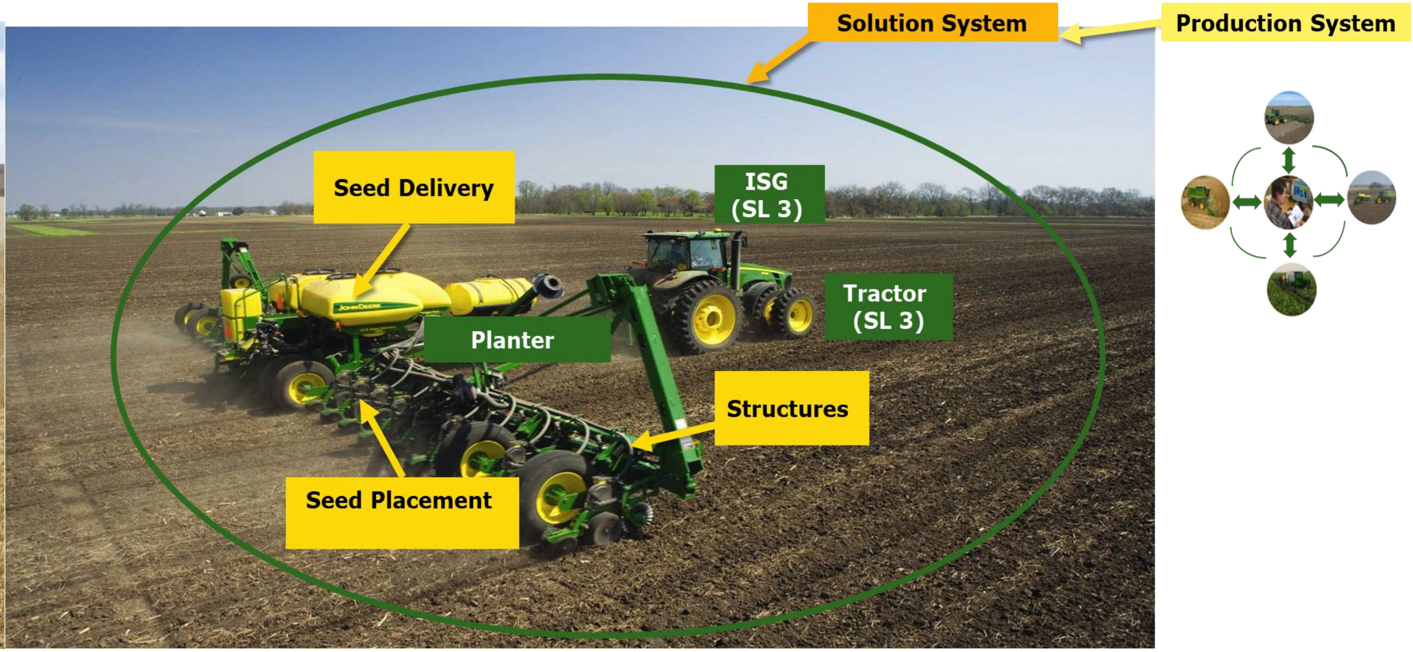
Golf & Sports Turf

Forestry

Engines &
Drivetrain

Government &
Military Sales

Rental Sales



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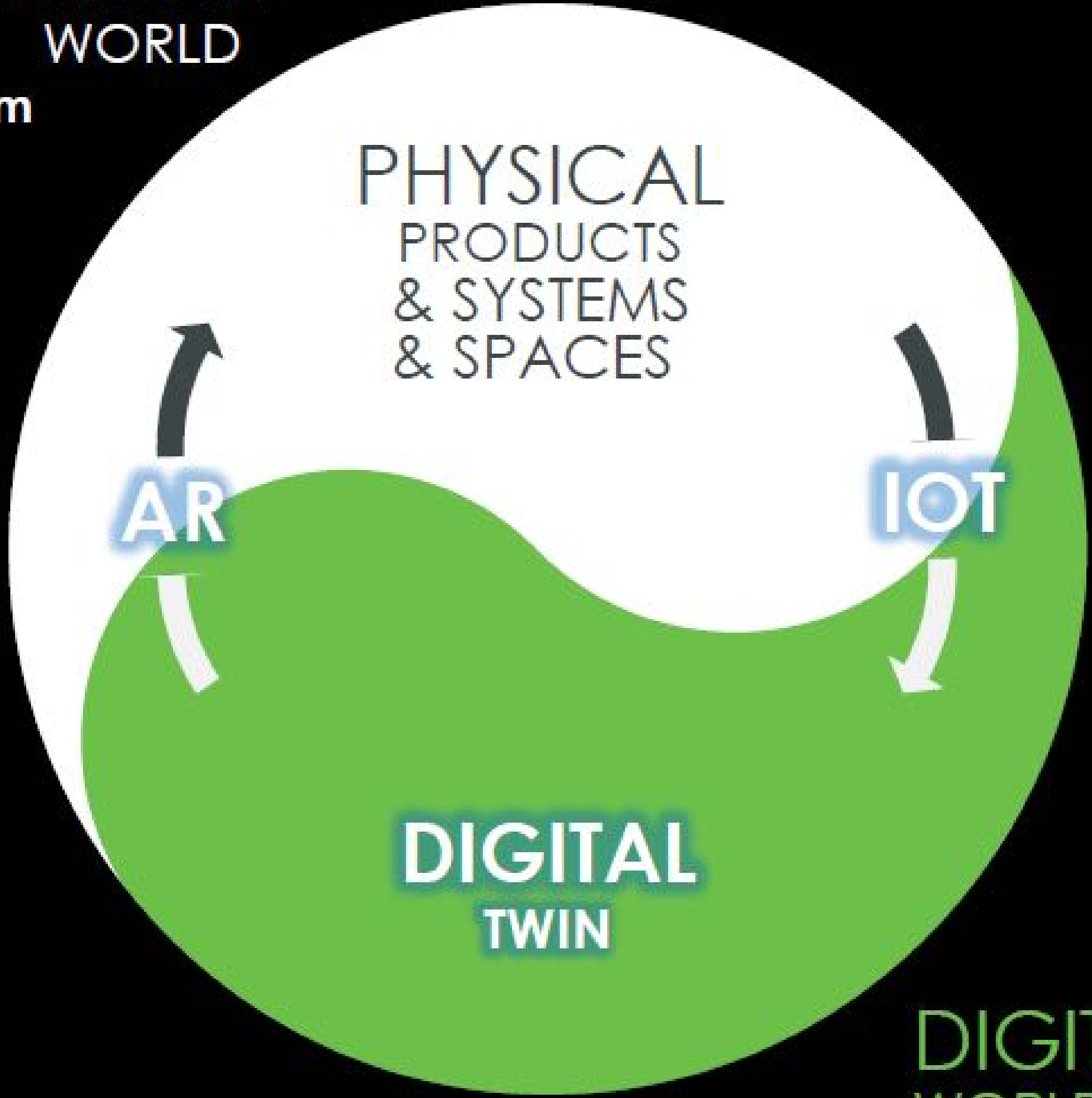
PHYSICAL
WORLD

Industrial Innovation Platform
>$100M Revenue
> 50% Bookings Growth FY16
1,200 End Customers
250 OEMs/Resellers
Ecosystem of SI's, partners

IoT & ANALYTICS | thingworx
AUGMENTED REALITY | vuforia
INDUSTRIAL CONNECTIVITY | kepware



PLM Solutions
>$1B Revenue
10% Bookings Growth FY16
28,000 End Customers
70% Direct Sales
30% VARs (~400)
Ecosystem of SI's, partners

CAD | creo
PLM | windchill
ALM | integrity
SLM | servigistics

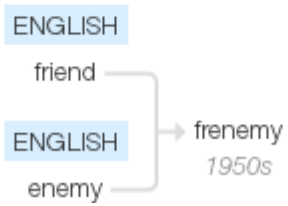
DIGITAL
WORLD

What is a Frenemy?

fren·e·my
/ˈfrenəmi/
noun
INFORMAL
noun: **frenemy**; plural noun: **frenemies**

a person with whom one is friendly despite a fundamental dislike or rivalry.
(Note: In this case more rivalry than dislike.)

Origin



1950s: blend of friend and enemy.

- OPM and SysML are different means of achieving MBSE, each with their own benefits, issues, supporters and detractors.
- But first, let’s look at some definitions.

Famous Frenemies

- Nicole Richie and Paris Hilton

- Jennifer Aniston and Courteney Cox

- Lauren Conrad and Heidi Montag

- Paris Hilton and Lindsay Lohan

- Selena Gomez and Miley Cyrus

- Whitney Port and Olivia Palermo

- Winona Ryder and Gwyneth Paltrow

- Selena Gomez and Demi Lovato

http://www.zimbio.com/Famous+Frenemies/articles

Working Together to achieve common goals

THE GOLDEN SPIKE

THE CHANNEL TUNNEL

The Systems Modeling language (SysML)

- Diagrams for system requirements, behavior, structure and parametric relationships.
  - Used to define high-level abstract systems down to detailed physical systems.
- Developed by the Object Management Group (OMG) and INCOSE.
  - Organizations from industry, academia, government, standards organizations, etc.
  - Many books on its basic notation and how to use SysML in large complex systems.
  - More than 10 commercial implementations of SysML tools are available, as well as freeware and shareware.
- Integrations between SysML tools and other SE tools such as Matlab, requirements engineering tools, PLM tools, process tools, etc.
  - Open System Lifecycle Collaboration (OSLC) has provided a standardized means of connecting tools that do not require point to point integrations.
  - Mandated for the development of many different military systems.
- SysML V2 is under development now.

Object Process Methodology (OPM)

- “Conceptual modeling language and methodology for capturing knowledge and designing systems.
  - Based on a minimal universal ontology of stateful objects and processes that transform them
  - OPM can be used to formally specify the function, structure, and behavior of artificial and natural systems in a large variety of domains.
  - A software package called OPCAT, for generating OPD and OPL, is freely available.

Object Process Methodology (OPM)

- OPM model represents the system under design or study in graphics and text for improved representation, understanding, communication, and learning.
  - In OPM, an object is a thing that exists, or might exist, physically or informatically.
  - A process is a thing that transforms an object by creating or consuming it, or by changing its state.
- The main author of OPM is Dov Dori
- OPM is bimodal; it is expressed both visually/graphically in Object-Process Diagrams (OPD) and verbally/textually in Object-Process Language (OPL), a set of automatically-generated sentences in a subset of English.
- OPM is an ISO standard OPM ISO 19450
- OPM is being further developed

Motivation for the paper

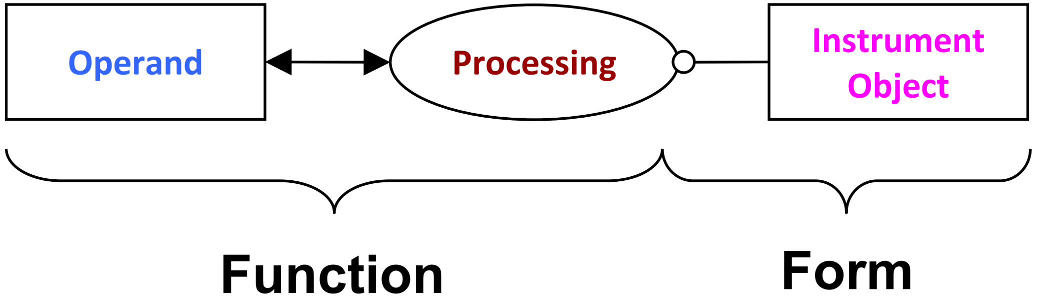
- OPM is used in systems engineering graduate courses at both the California Institute of Technology (CalTech) and the Massachusetts Institute of Technology (MIT).
  - Students graduating from these institutions are struggling to integrate the differing styles, philosophies, concepts and processes of SysML and OPM.
- A literature search reveals some papers that contrast SysML and OPM, but none that describe how the two can work together.
- This presentation discusses a synergy rather than promoting one language over another.

Ref: Systems Modeling Languages: OPM Versus SysML

Yariv Grobshtein, Valeriya Perelman, Eliyahu Safra, Dov Dori

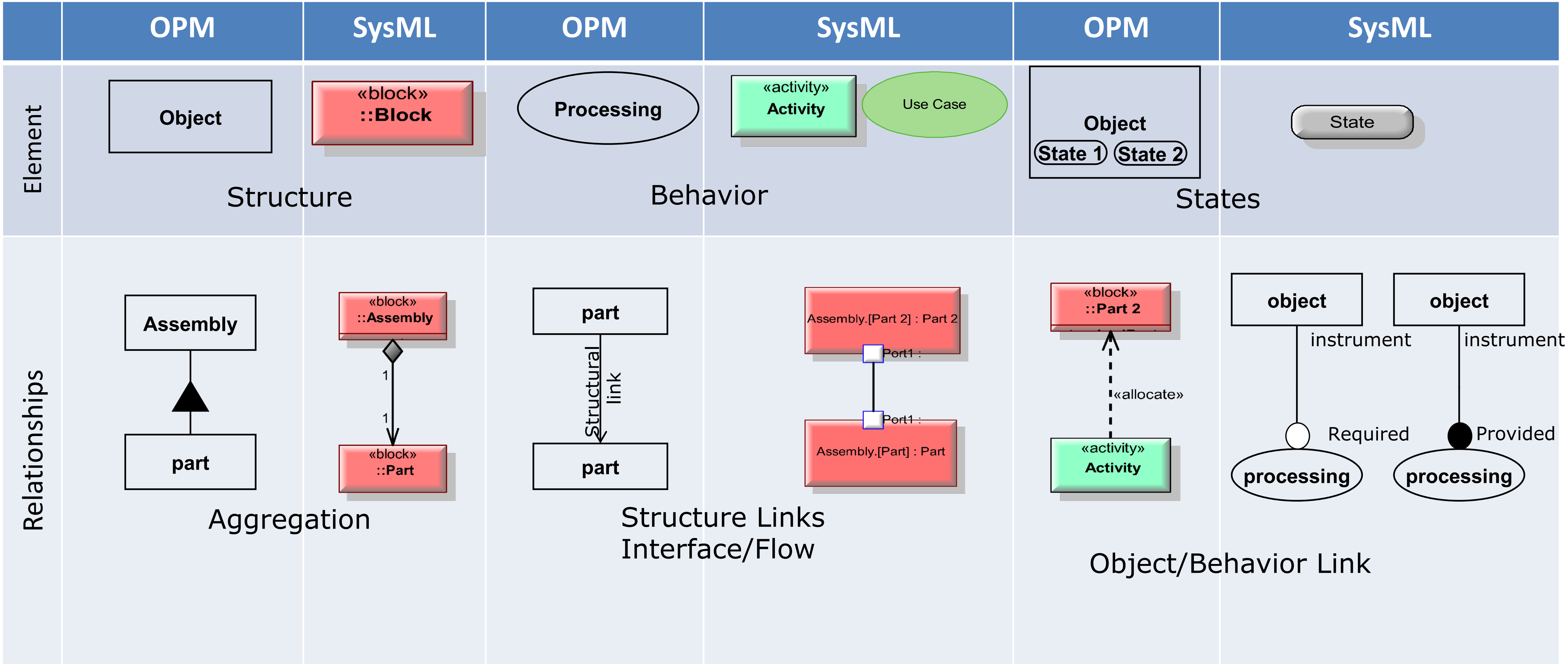
OPM

Canonical Architecture Representation with OPD

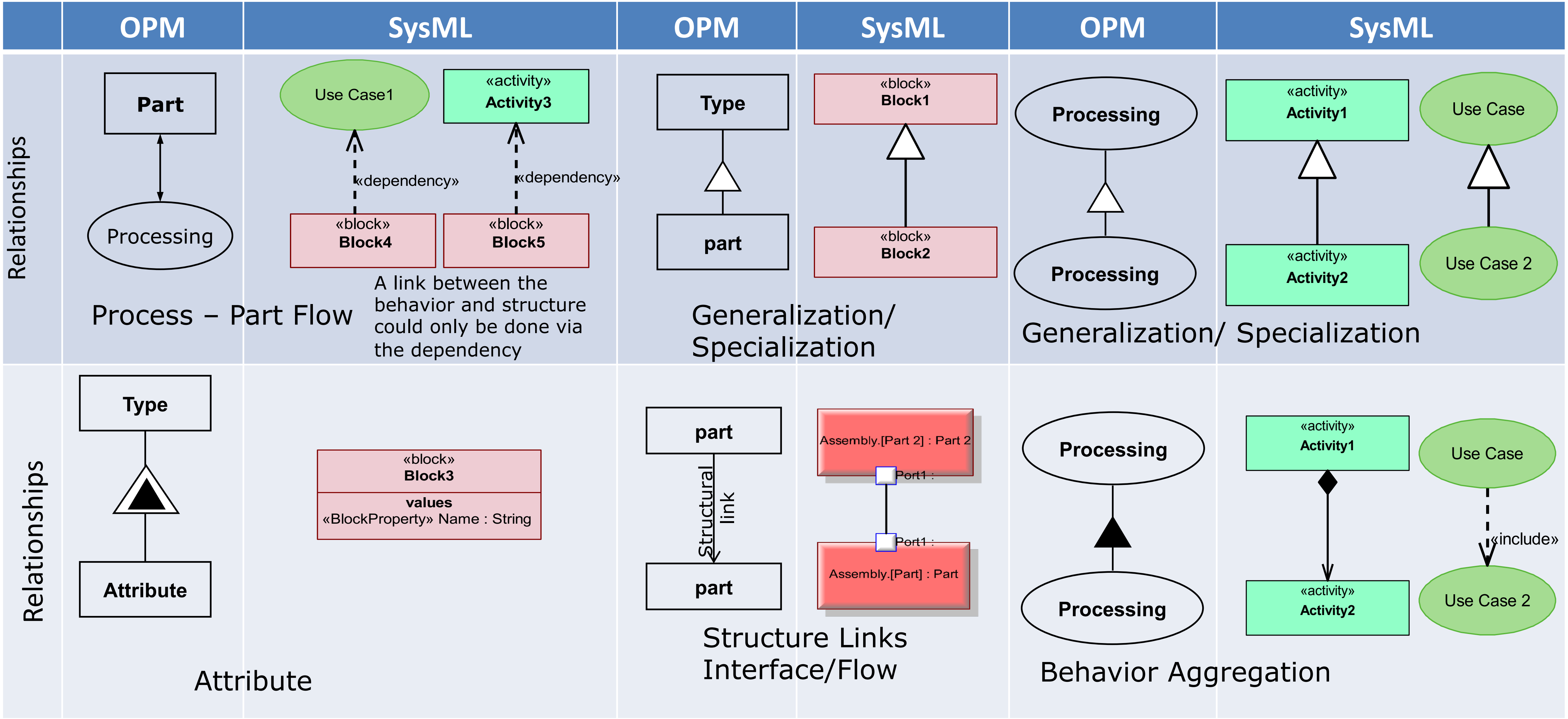


- Architecture is made up of operands + processes (functions) plus instrument objects (form)
- Examples:
  - Image is captured by digital camera
  - Homeowner is sheltered by a house
  - Traveler is safeguarded by evacuation instructions
  - Vehicle is supported (in transit) by bridge

Two Common languages for modeling: SysML v/s OPM (notations)



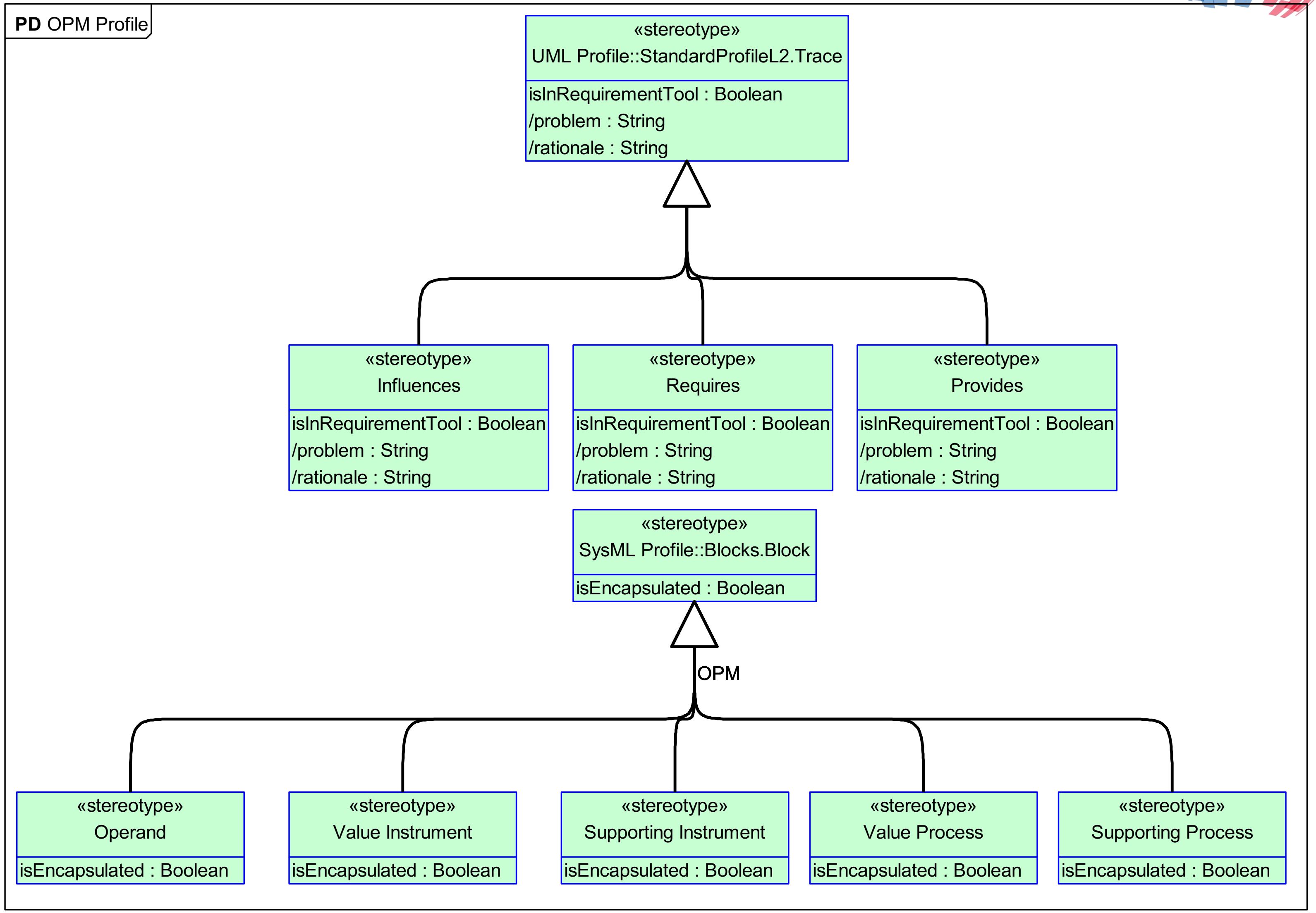
Two Common languages for modeling SysML v/s OPM (notations)



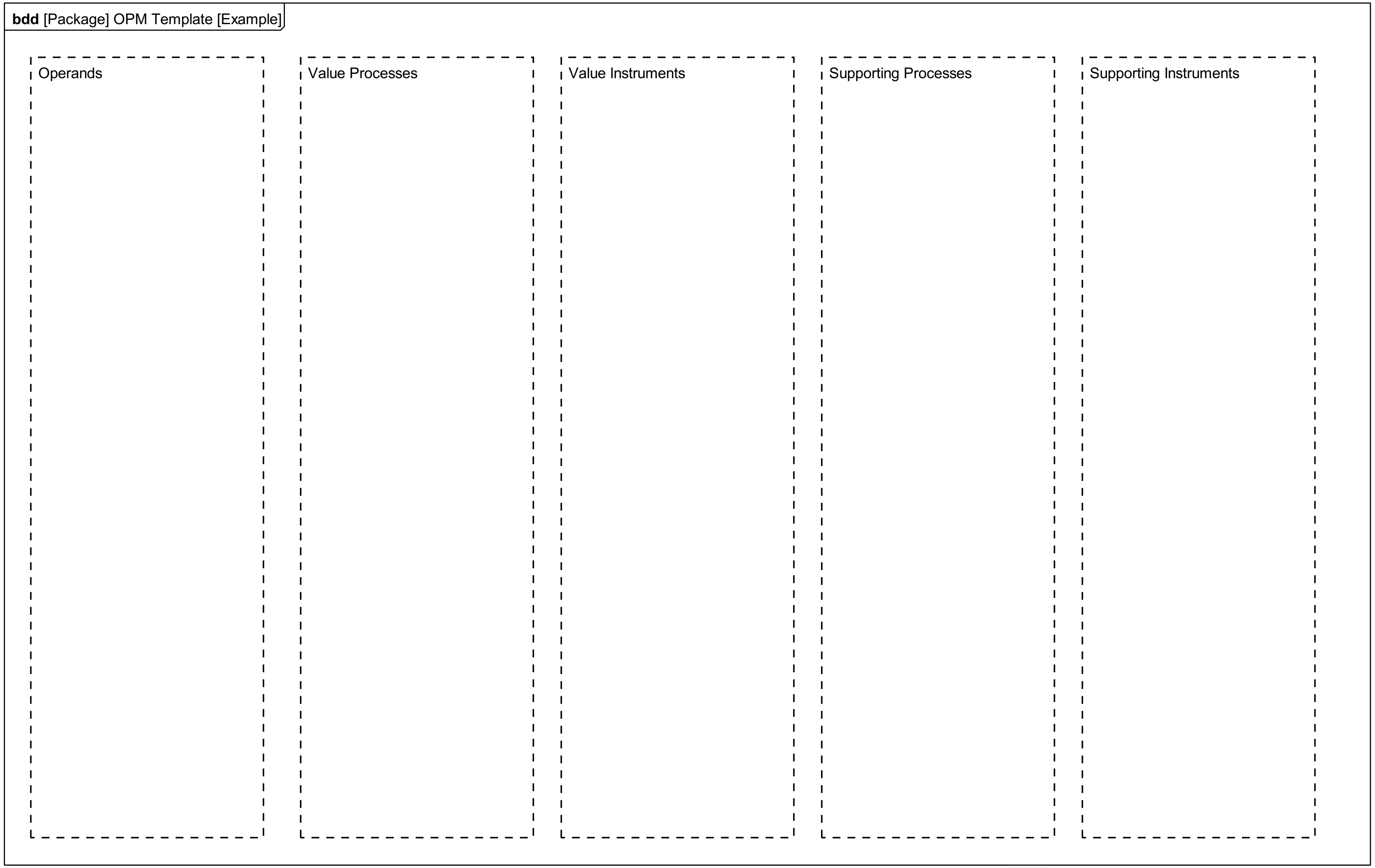
Combining the Two

Profile Diagram

- Simple Profile
  - Extends SysML
  - Defines elements as extensions of Blocks
  - Processes modeled as blocks as well
  - Relationships are extensions of Trace
  - "Open Dot" is requires, "Closed Dot" is provides
- Elements can be used as part of SysML model
- Basic diagram is the BDD
  - Uses SysML notation
- Some limitations

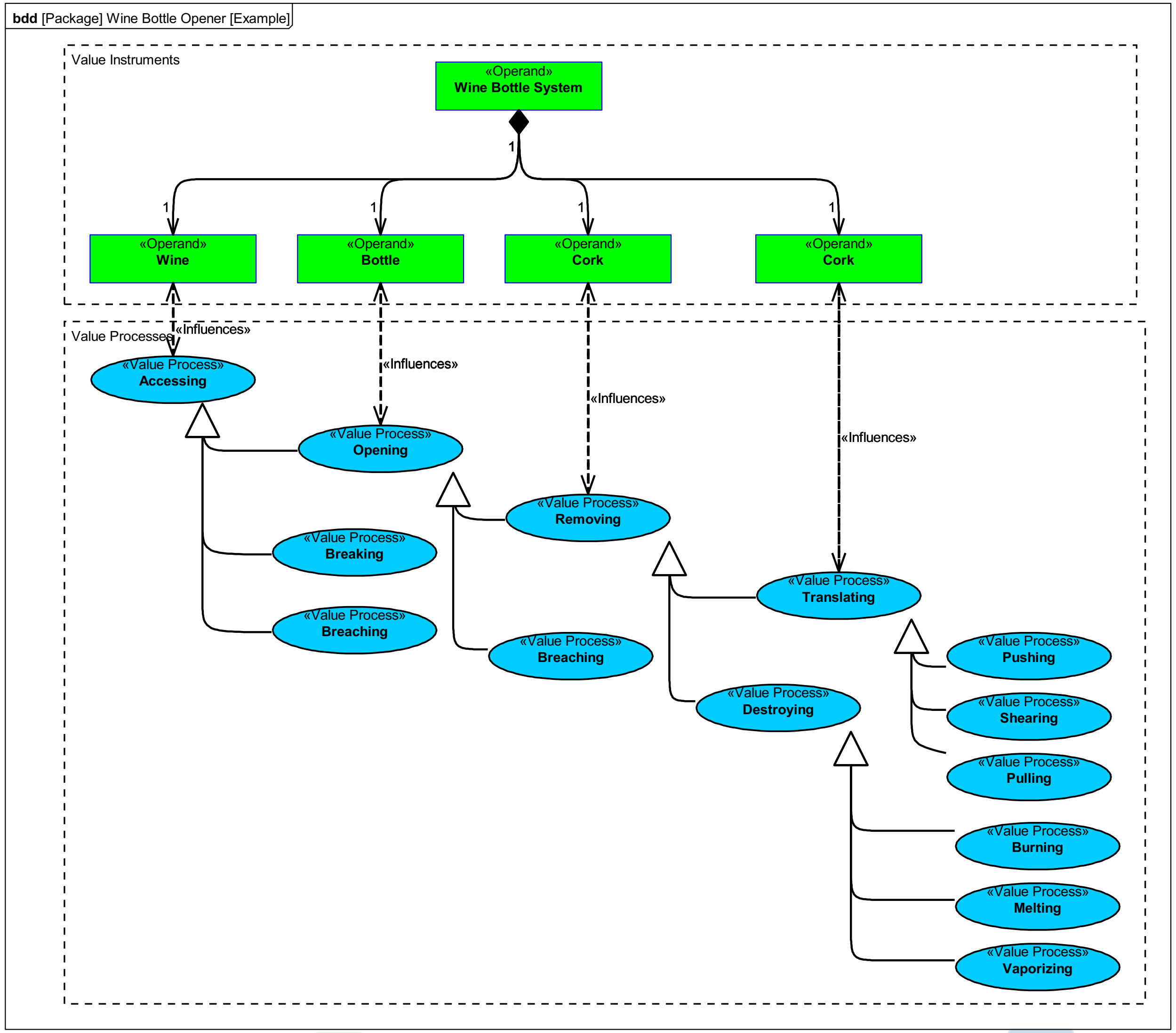


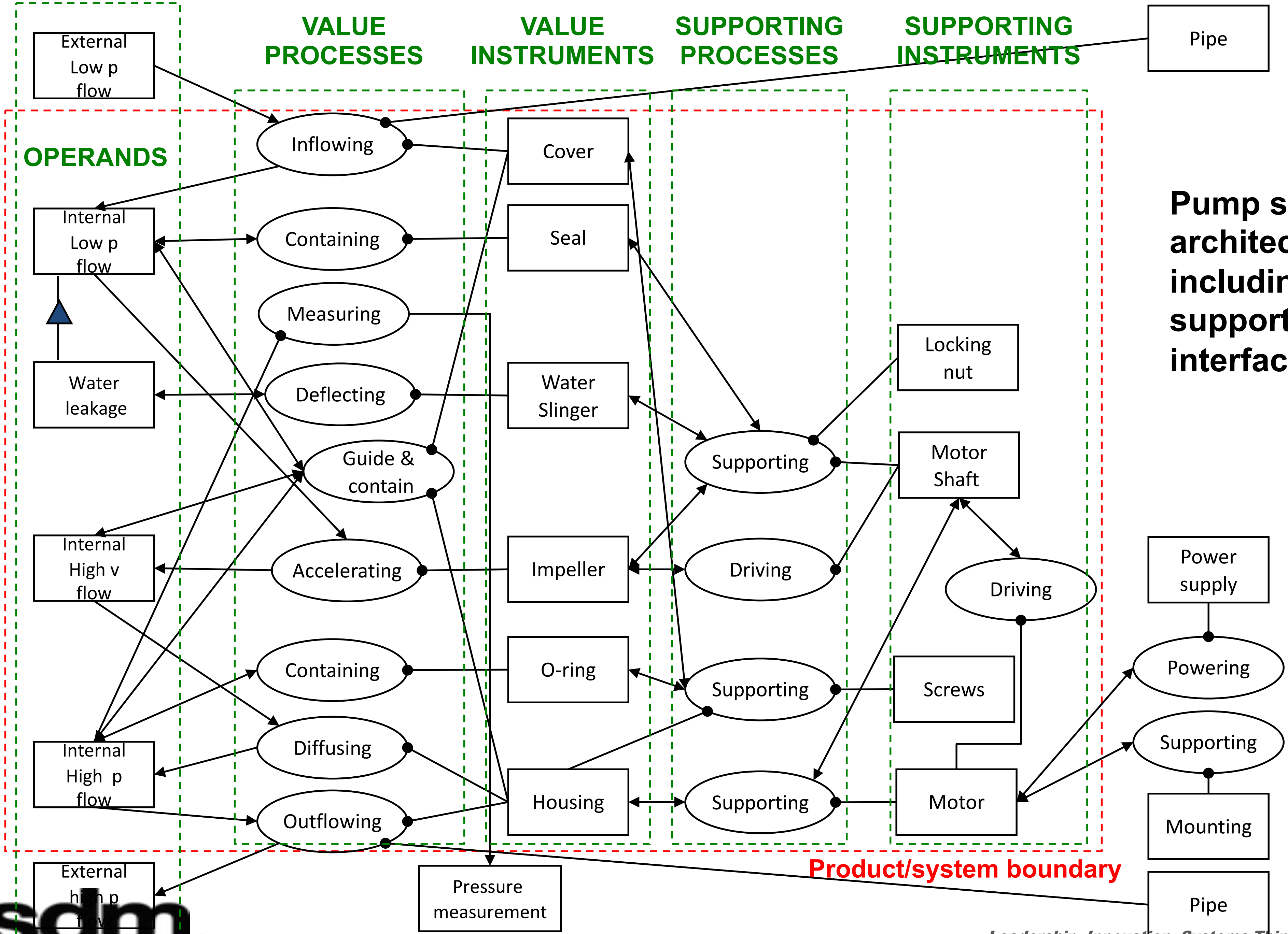
Template for Diagrams



Bottle Opener Example

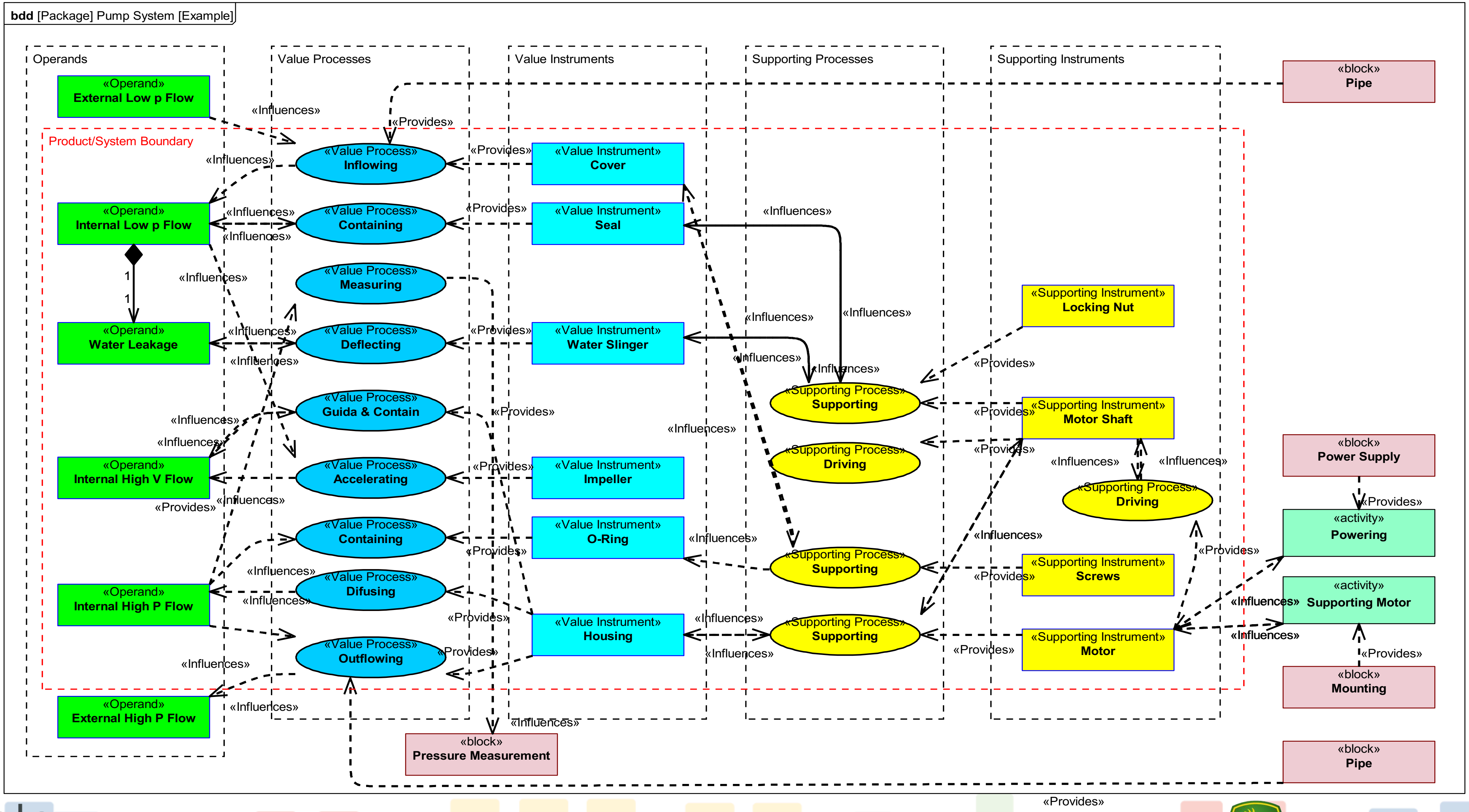
- Defines components of Wine Bottle system
- Defines processes of different varieties for opening wine bottles
  - Opening, removing, breaching, destroying, vaporizing, etc.
  - Defined using inheritance.





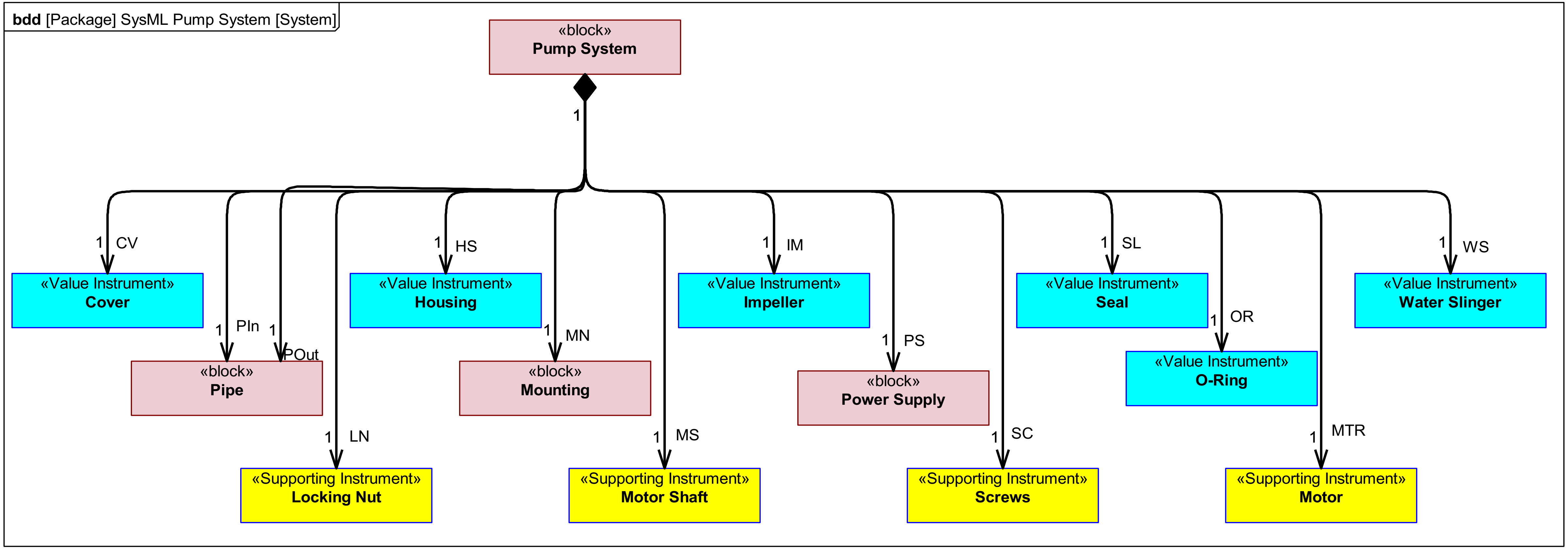
Pump system architecture including supporting and interfacing

Pump System Example

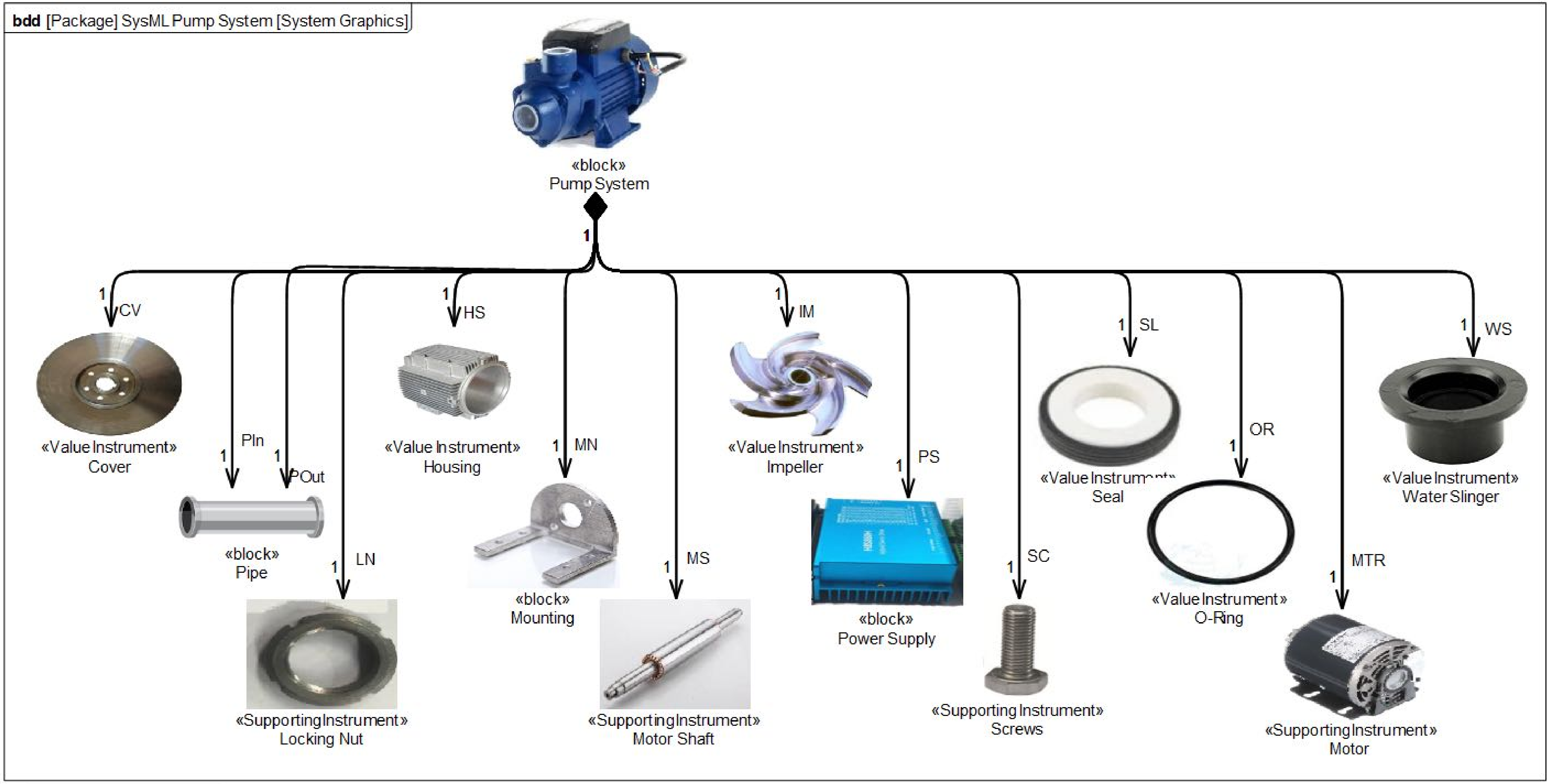


Pump System Structural Breakdown

- Pump System and its components.
- A combination of Value and Supporting Instruments and Blocks

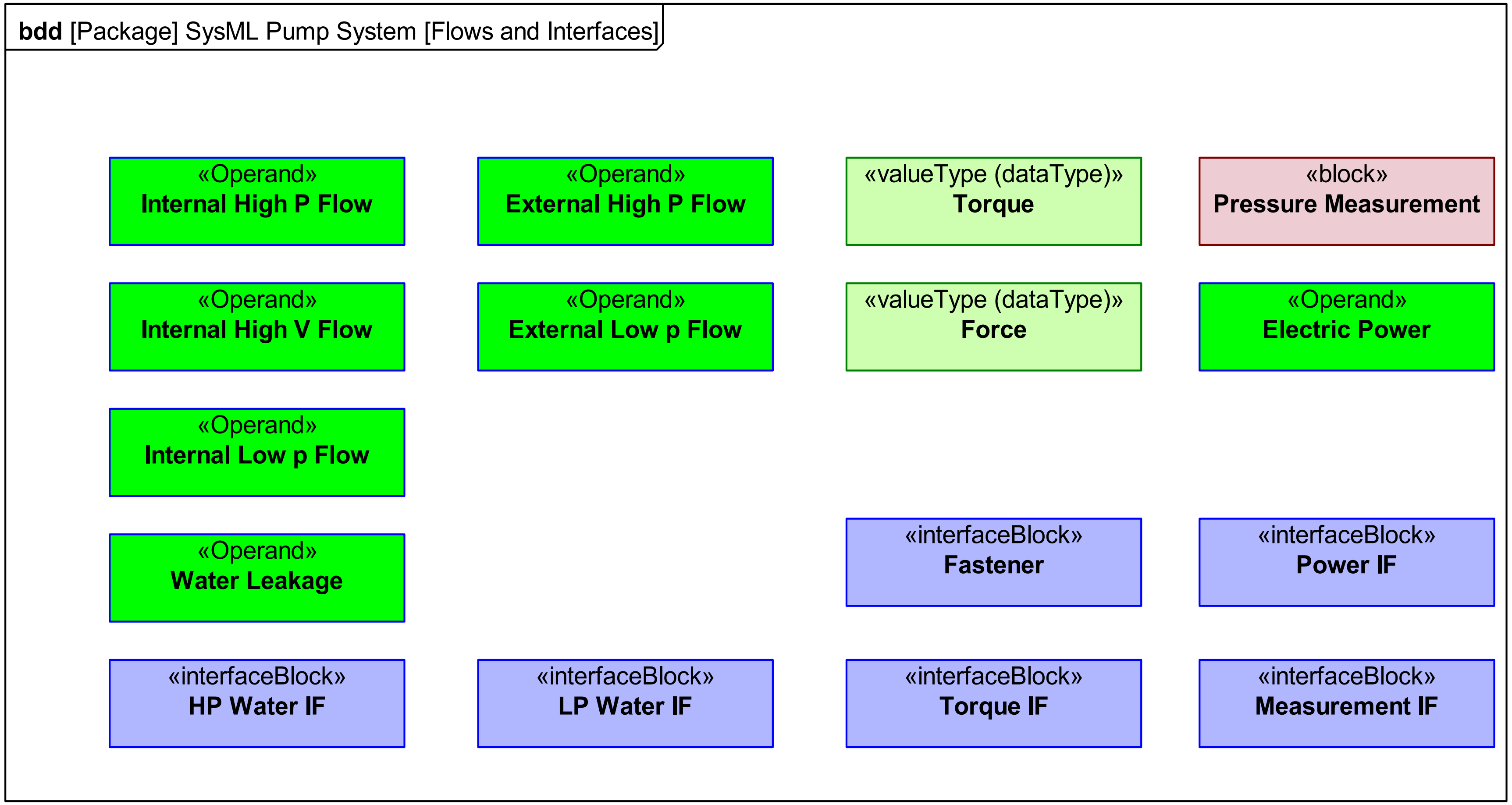


Pump System Structural Breakdown w/Graphics



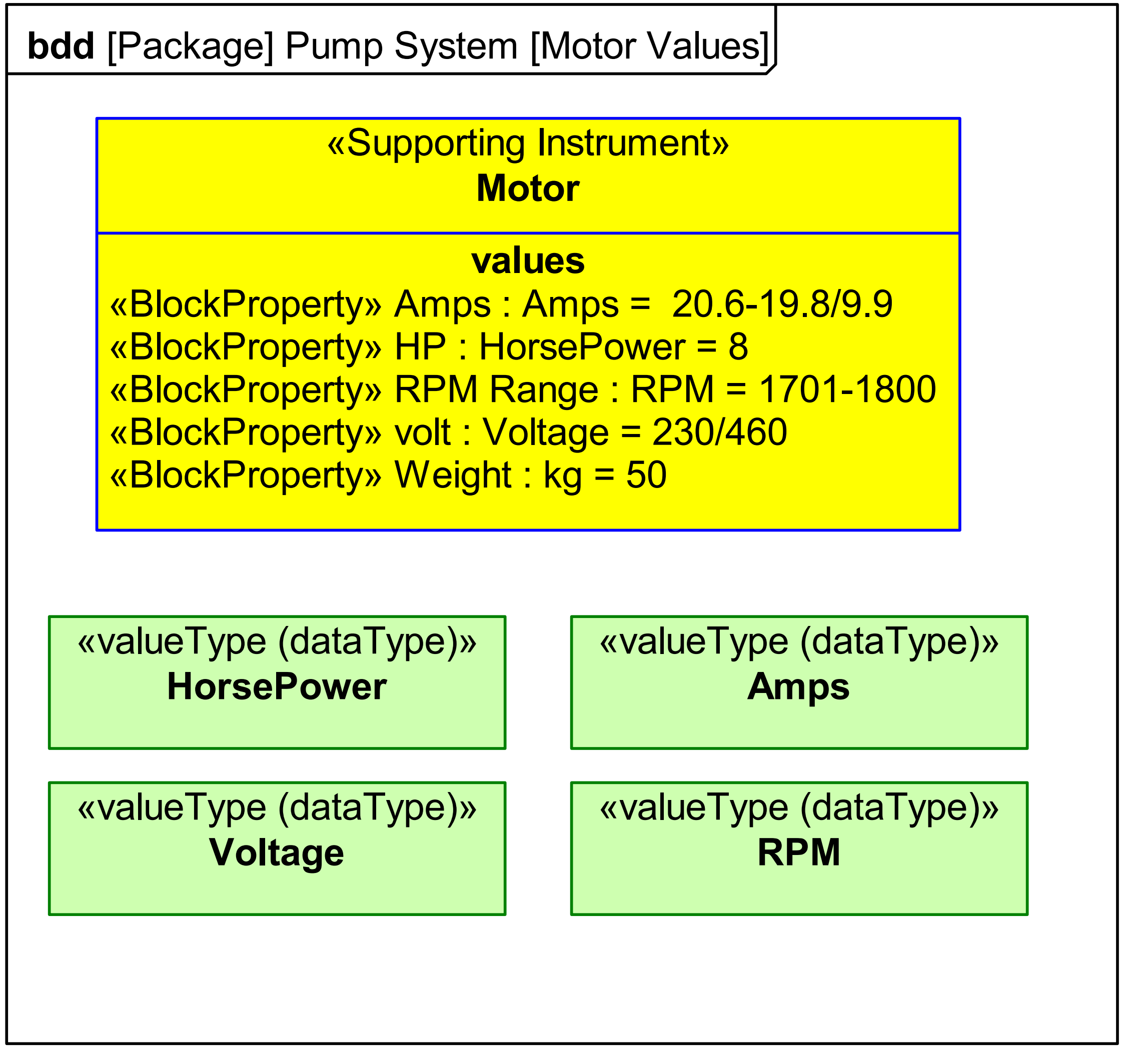
Flows and Interfaces

- Elements taken from the OPM example
- Torque and Force added as Value Types
- Interfaces added to define how systems interact

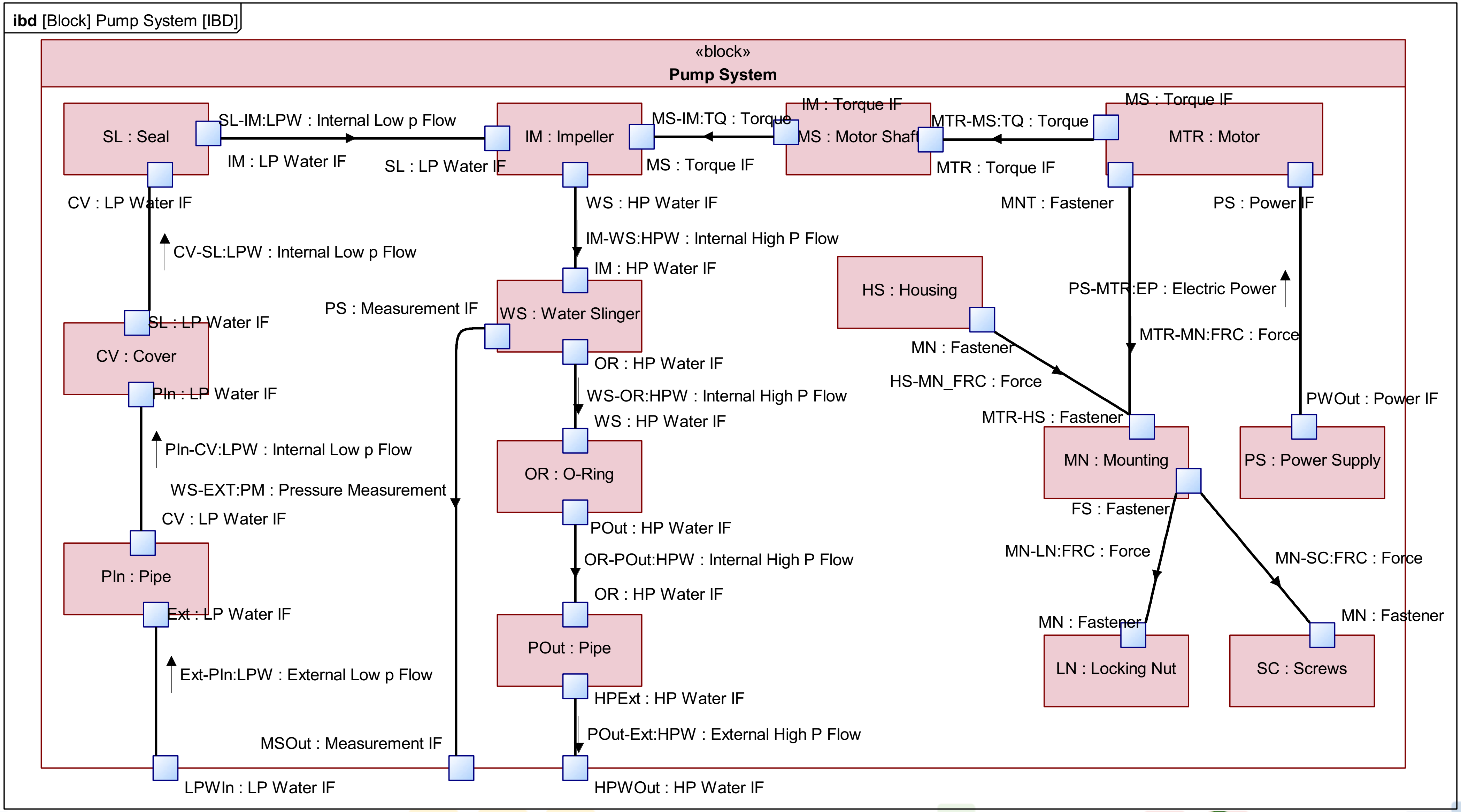


Motor Value Properties

- System characteristics can be modeled as block properties
- Block properties can be used in parametric equations
- These will be useful later for trade space Pareto analysis

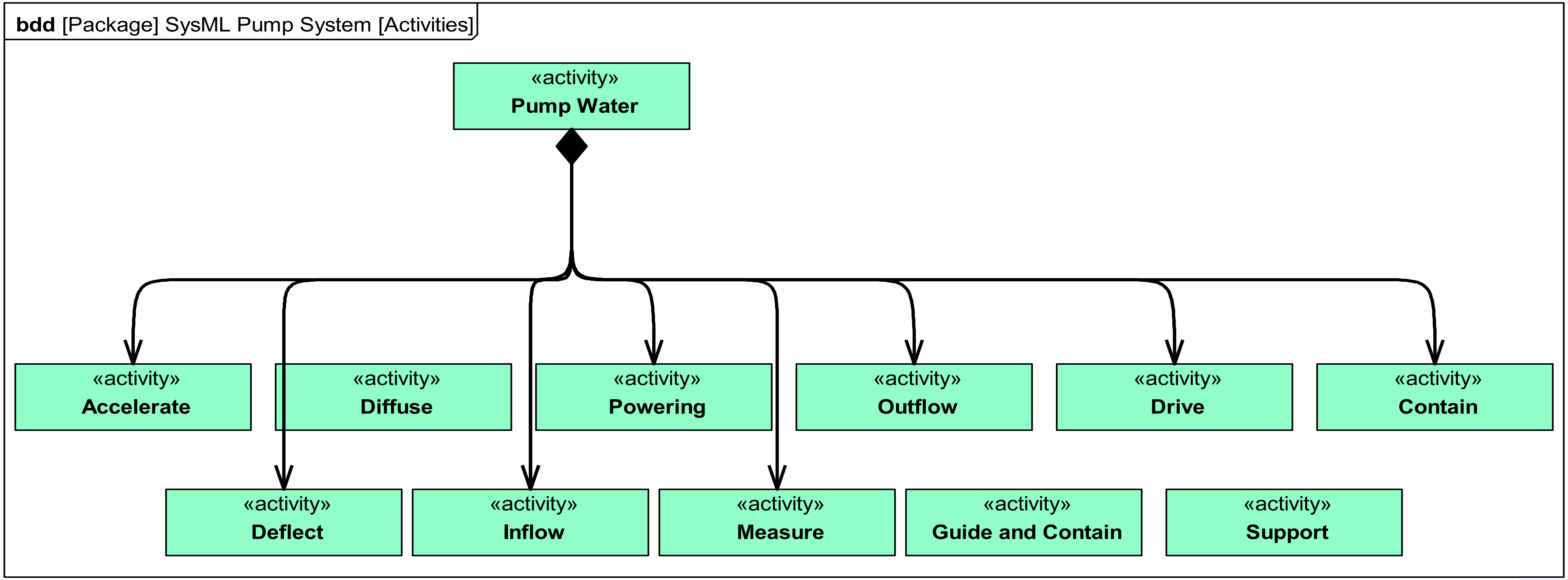


System Internal Structure



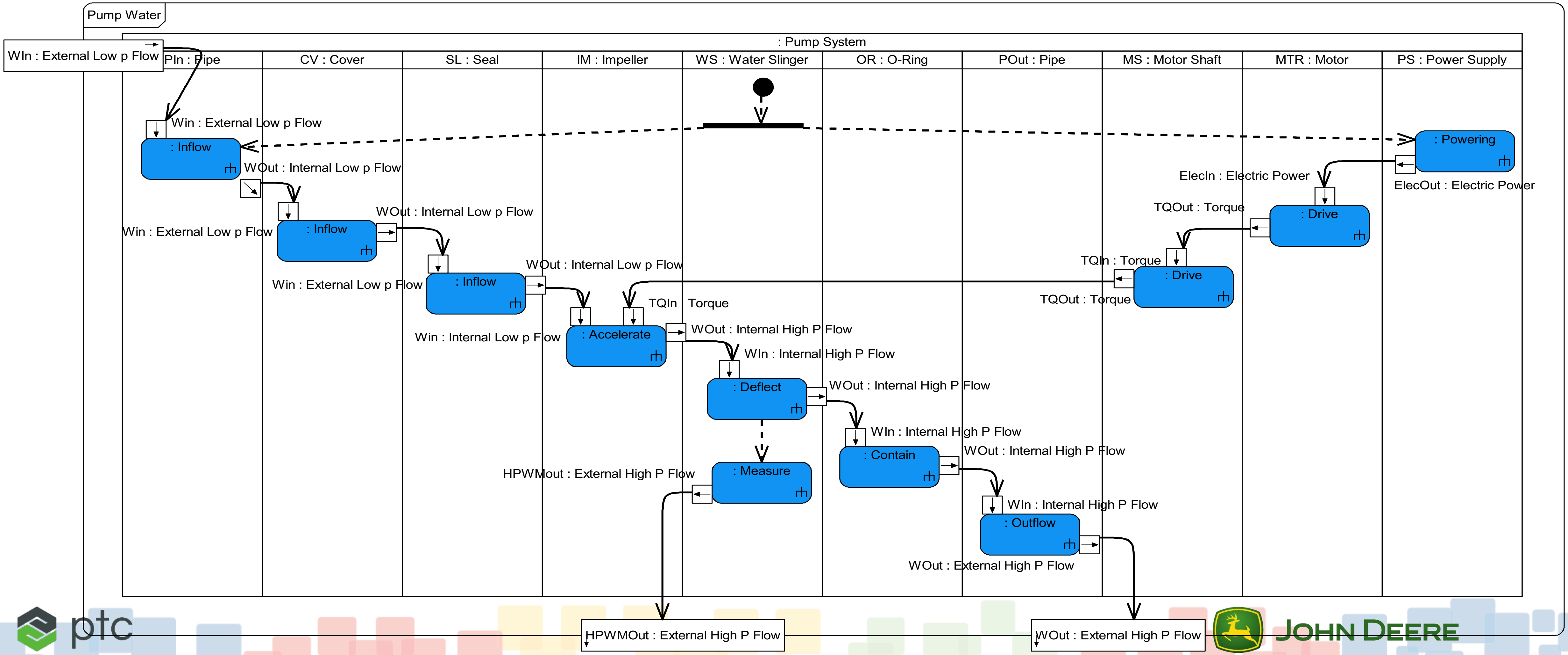
System Functional Breakdown

- Activities created from the original OPM elements
- Guide and Contain, and Support were not used.



System Activity Diagram

- Defined as a continuous, parallel sequence.
- Similar to the SysML V1 Distiller example



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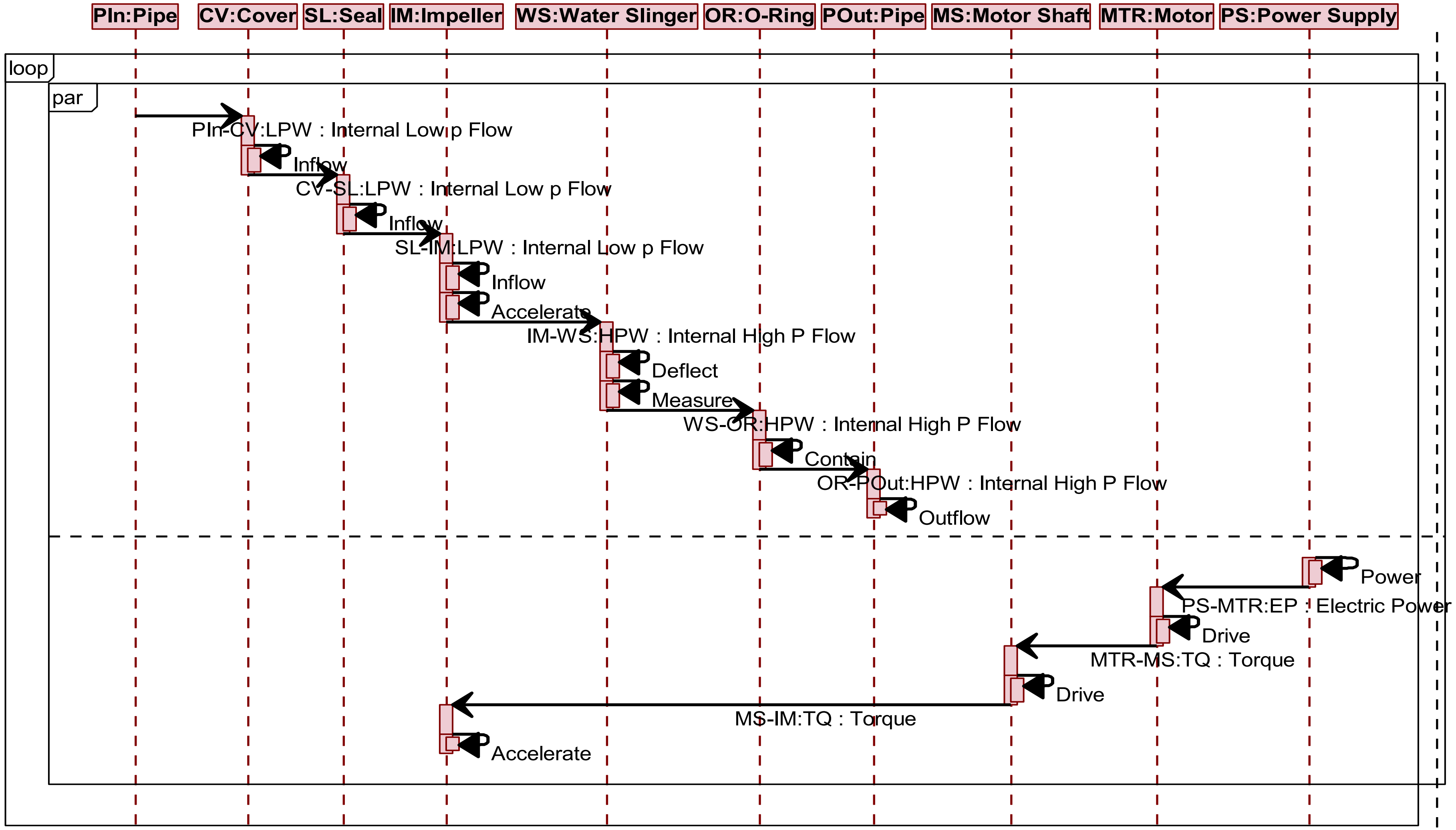
Pump Sequence Diagram

- Defines the system interactions in a defined order and links behavior.

Description

loop
par
Low P water flow
Flow thru
Low P water flow
Flow thru
Low P water flow
Flow thru
Energize water
High P water flow
Deflect
Measure Pressure
High P water flow
Contain Water
High P water flow
Flow thru
also par
Generate Power
Power Motor
Drive Motor
Torque transfer
Drive Motor Shaft
High P water flow
Energize water
end par
Until Shutdown



ISO 15288 and MBSE

What does it mean to us?

Mission

Why?

What is TradeSpace?

What Benefit?

Concept

Examples

Design

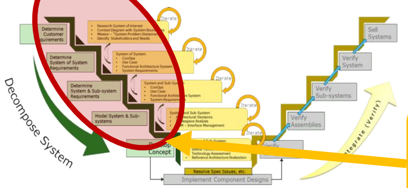
How to make one?

- ❑ OPM
  - ❑ Evaluate Concepts
  - ❑ Remove Opinions & Bias
  - ❑ Large Complex Decisions
  - ❑ Not for A to B Comparisons
  - ❑ Tradespace Analysis

- ❑ SysML
  - ❑ Detailed Modeling of Concept(s)
  - ❑ Evaluate Concept(s)
  - ❑ Linking to lifecycle artifacts
  - ❑ Parametrics
  - ❑ SE Tool Integration

What does it mean to us?

Mission Inclusion



OPM Application

Arch. Option (Function Based)

What are comparison parameters?

Assess Relative Cost Within function

Assess Relative Utility Importance

Assess Utility Perf. Parameters

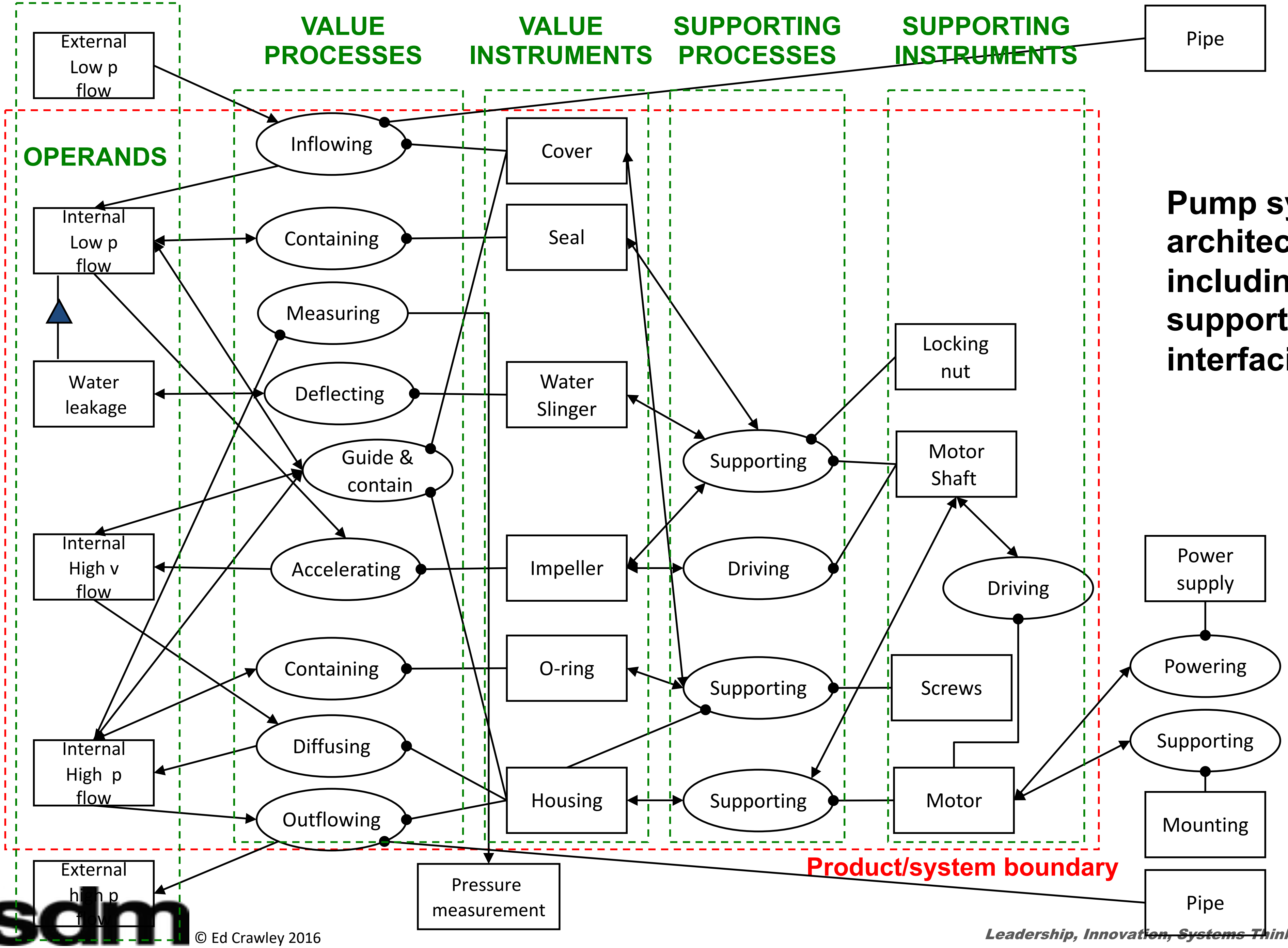
Evaluate Combinations

Extract Pareto Front

Filter Concepts as needed

Determine Optimal Solutions

SysML Application



Pump system architecture including supporting and interfacing

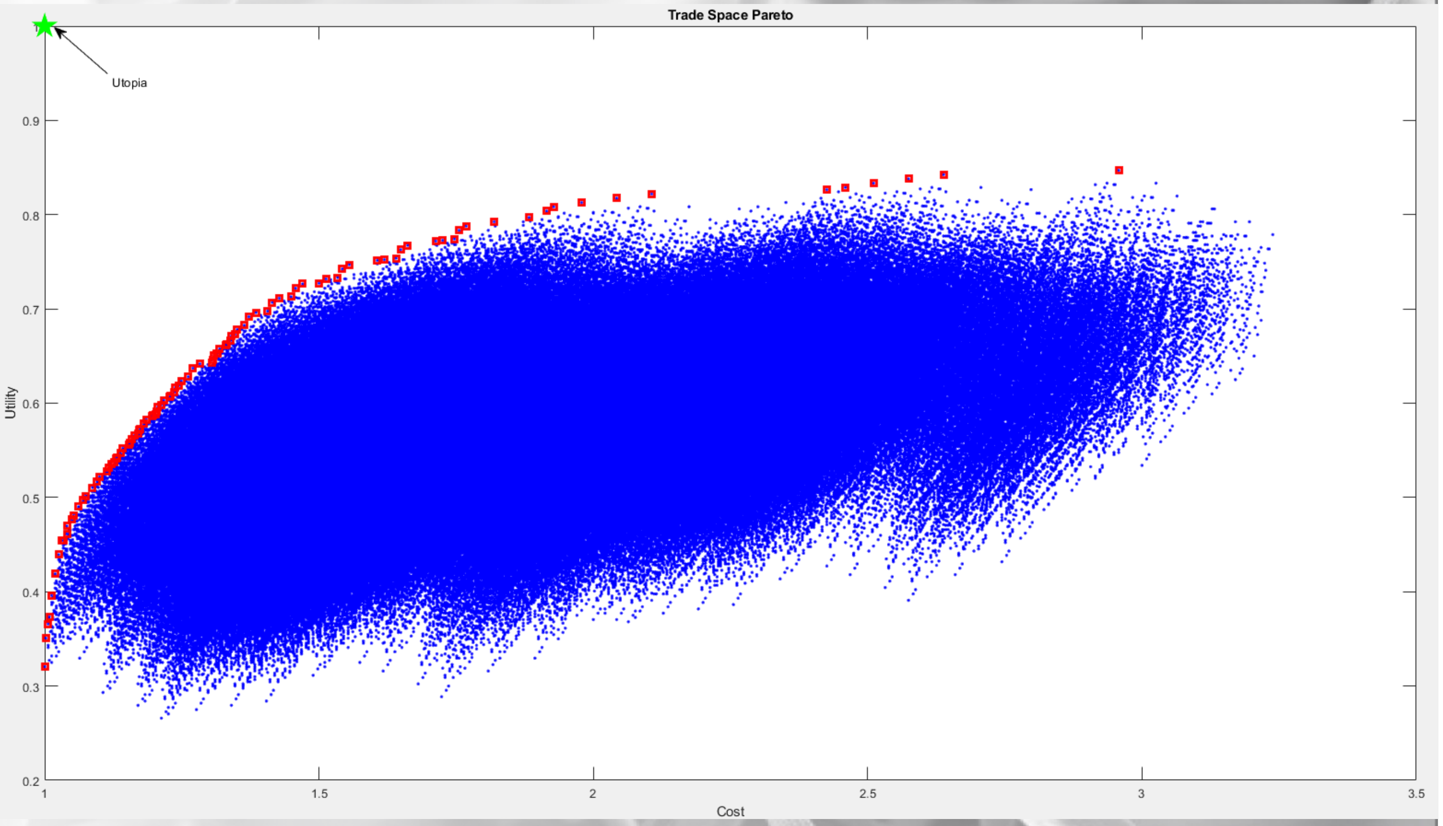
Architectural Options – Morphological Matrix

ID	Architectural Decision	Option 1	Option 2	Option 3	Option 4	Option 5	Option 6	Classification	Notes
Plan	Planning (Path)	Manual	Assisted	Automated				Function	
Comm	Communicating (State)	Verbal	Base: Cloud + 4G/5G	Base + WiFi	WiFi (M2M only)	Bluetooth (M2M only)		Form	Communicating machine state and machine location
Detect	Avoiding (Obstacles)	Manual	GPS/RTK + Stereo Cameras	GPS/RTK + Stereo Cameras + Radar	Lidar + Radar			Function	Obstacle avoidance for harvester and haulage unit
Navigate	Navigating (Path)	Manual	Assisted	Coordinated	Automated	Supervised	Autonomous	Function	Navigating planned paths for harvester and haulage unit
Harvest	Gathering (Plants)	Manual	Assisted	Coordinated	Automated	Supervised	Autonomous	Function	Gathering, cutting and cleaning processes of harvester
Transfer	Transferring (Commodity)	Shovel	Auger	Belt	Air			Form	Moving material from harvester to haulage unit
Haul	Hauling (Commodity)	Manual	Assisted	Coordinated	Automated	Supervised	Autonomous	Function	Aligning, receiving and unloading commodity
Prod	Productivity (Harvester)	AA t/hr	AA*1.15 t/hr	AA*1.25 t/hr	AA*1.50 t/hr	AA*1.75 t/hr			Small machine AA t/hr, large machine AA*1.75 t/hr
Mass	Weight (Harvester)	10,000	20,000	30,000	40,000			Form	19,262 kg Grain 19,500 kg Cane 30,000 kg Cotton

Arch. Option (Function Based) → What are comparison parameters? → Assess Relative Cost Within function → Assess Relative Utility Importance → Assess Utility Perf. Parameters → **Evaluate Combinations** → Filter Concepts as needed

Trade Space Pareto

Create Pareto chart with all possible combinations (~1.04M options)



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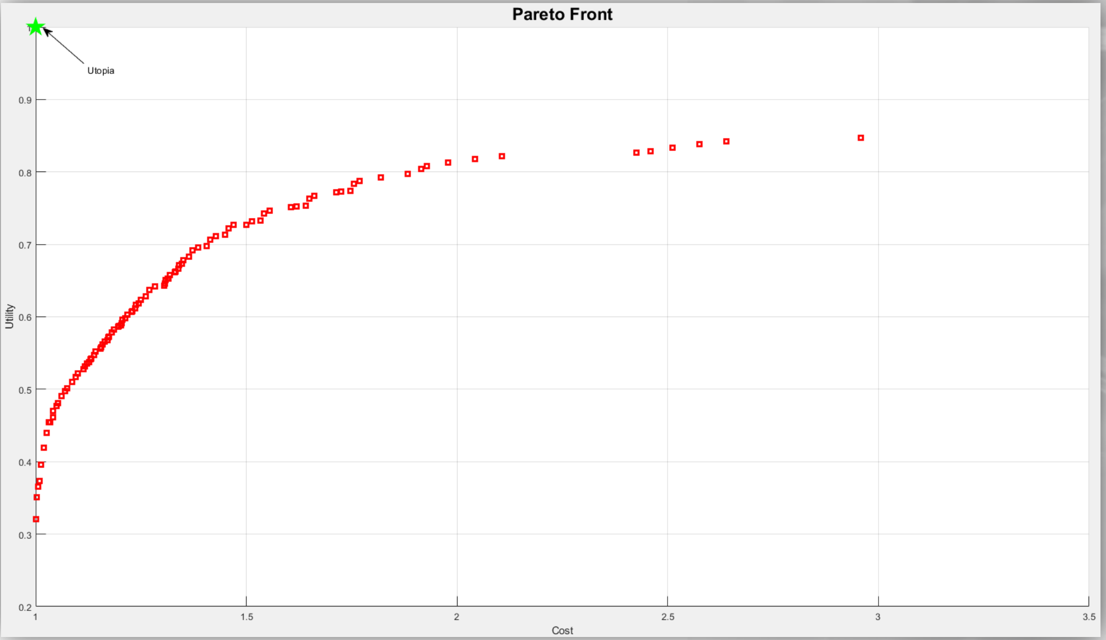
Arch. Option (Function Based) → What are comparison parameters? → Assess Relative Cost Within function → Assess Relative Utility Importance → Assess Utility Perf. Parameters → **Evaluate Combinations** → Filter Concepts as needed

Trade Space Pareto Front



Combination	Cost	Utility	Comm	Detect	Harvest	Path	Transfer	Haulage	Navigation	Weight	Productivity
258465	2.957447	0.84697	B_WIFI	G_SC_R	Harv_5	Auto	Pneumatic	H_5	E_5	10_Kg	175
258345	2.638298	0.842424	B_WIFI	G_SC_R	Harv_5	Auto	Pneumatic	H_4	E_5	10_Kg	175
258225	2.574468	0.837879	B_WIFI	G_SC_R	Harv_5	Auto	Pneumatic	H_3	E_5	10_Kg	175
258105	2.510638	0.833333	B_WIFI	G_SC_R	Harv_5	Auto	Pneumatic	H_2	E_5	10_Kg	175
257985	2.459574	0.828788	B_WIFI	G_SC_R	Harv_5	Auto	Pneumatic	H_1	E_5	10_Kg	175
249825	2.425532	0.826515	B_WIFI	G_SC_R	Harv_4	Auto	Pneumatic	H_5	E_5	10_Kg	175
249705	2.106383	0.82197	B_WIFI	G_SC_R	Harv_4	Auto	Pneumatic	H_4	E_5	10_Kg	175
249585	2.042553	0.817424	B_WIFI	G_SC_R	Harv_4	Auto	Pneumatic	H_3	E_5	10_Kg	175
249465	1.978723	0.812879	B_WIFI	G_SC_R	Harv_4	Auto	Pneumatic	H_2	E_5	10_Kg	175
249345	1.92766	0.808333	B_WIFI	G_SC_R	Harv_4	Auto	Pneumatic	H_1	E_5	10_Kg	175
249225	1.914894	0.803788	B_WIFI	G_SC_R	Harv_4	Auto	Pneumatic	H_0	E_5	10_Kg	175
249565	1.882979	0.79697	B_WIFI	G_SC_R	Harv_4	Auto	Pneumatic	H_3	E_4	10_Kg	175
249445	1.819149	0.792424	B_WIFI	G_SC_R	Harv_4	Auto	Pneumatic	H_2	E_4	10_Kg	175
249325	1.768085	0.787879	B_WIFI	G_SC_R	Harv_4	Auto	Pneumatic	H_1	E_4	10_Kg	175
249205	1.755319	0.783333	B_WIFI	G_SC_R	Harv_4	Auto	Pneumatic	H_0	E_4	10_Kg	175
248605	1.746809	0.774242	B_WIFI	G_SC_R	Harv_4	Auto	Belt	H_1	E_4	10_Kg	175
249324	1.725532	0.772727	B_WIFI	G_SC_R	Harv_4	Auto	Pneumatic	H_1	E_4	10_Kg	150
240805	1.712766	0.77197	B_WIFI	G_SC_R	Harv_3	Auto	Pneumatic	H_2	E_4	10_Kg	175
240685	1.661702	0.767424	B_WIFI	G_SC_R	Harv_3	Auto	Pneumatic	H_1	E_4	10_Kg	175
240565	1.648936	0.762879	B_WIFI	G_SC_R	Harv_3	Auto	Pneumatic	H_0	E_4	10_Kg	175
239965	1.640426	0.753788	B_WIFI	G_SC_R	Harv_3	Auto	Belt	H_1	E_4	10_Kg	175
240684	1.619149	0.752273	B_WIFI	G_SC_R	Harv_3	Auto	Pneumatic	H_1	E_4	10_Kg	150
232165	1.606383	0.751515	B_WIFI	G_SC_R	Harv_2	Auto	Pneumatic	H_2	E_4	10_Kg	175
232045	1.555319	0.74697	B_WIFI	G_SC_R	Harv_2	Auto	Pneumatic	H_1	E_4	10_Kg	175
231925	1.542553	0.742424	B_WIFI	G_SC_R	Harv_2	Auto	Pneumatic	H_0	E_4	10_Kg	175
231325	1.534043	0.733333	B_WIFI	G_SC_R	Harv_2	Auto	Belt	H_1	E_4	10_Kg	175
232044	1.512766	0.731818	B_WIFI	G_SC_R	Harv_2	Auto	Pneumatic	H_1	E_4	10_Kg	150
231924	1.5	0.727273	B_WIFI	G_SC_R	Harv_2	Auto	Pneumatic	H_0	E_4	10_Kg	150
223405	1.470213	0.726515	B_WIFI	G_SC_R	Harv_1	Auto	Pneumatic	H_1	E_4	10_Kg	175
223285	1.457447	0.72197	B_WIFI	G_SC_R	Harv_1	Auto	Pneumatic	H_0	E_4	10_Kg	175
222685	1.448936	0.712879	B_WIFI	G_SC_R	Harv_1	Auto	Belt	H_1	E_4	10_Kg	175
223404	1.42766	0.711364	B_WIFI	G_SC_R	Harv_1	Auto	Pneumatic	H_1	E_4	10_Kg	150
223284	1.414894	0.706818	B_WIFI	G_SC_R	Harv_1	Auto	Pneumatic	H_0	E_4	10_Kg	150
222684	1.406383	0.697727	B_WIFI	G_SC_R	Harv_1	Auto	Belt	H_1	E_4	10_Kg	150
223403	1.385106	0.696212	B_WIFI	G_SC_R	Harv_1	Auto	Pneumatic	H_1	E_4	10_Kg	125
223283	1.37234	0.691667	B_WIFI	G_SC_R	Harv_1	Auto	Pneumatic	H_0	E_4	10_Kg	125
222683	1.36383	0.682576	B_WIFI	G_SC_R	Harv_1	Auto	Belt	H_1	E_4	10_Kg	125
222563	1.351064	0.67803	B_WIFI	G_SC_R	Harv_1	Auto	Belt	H_0	E_4	10_Kg	125

84 valid concepts on Pareto front
(102 total concepts)

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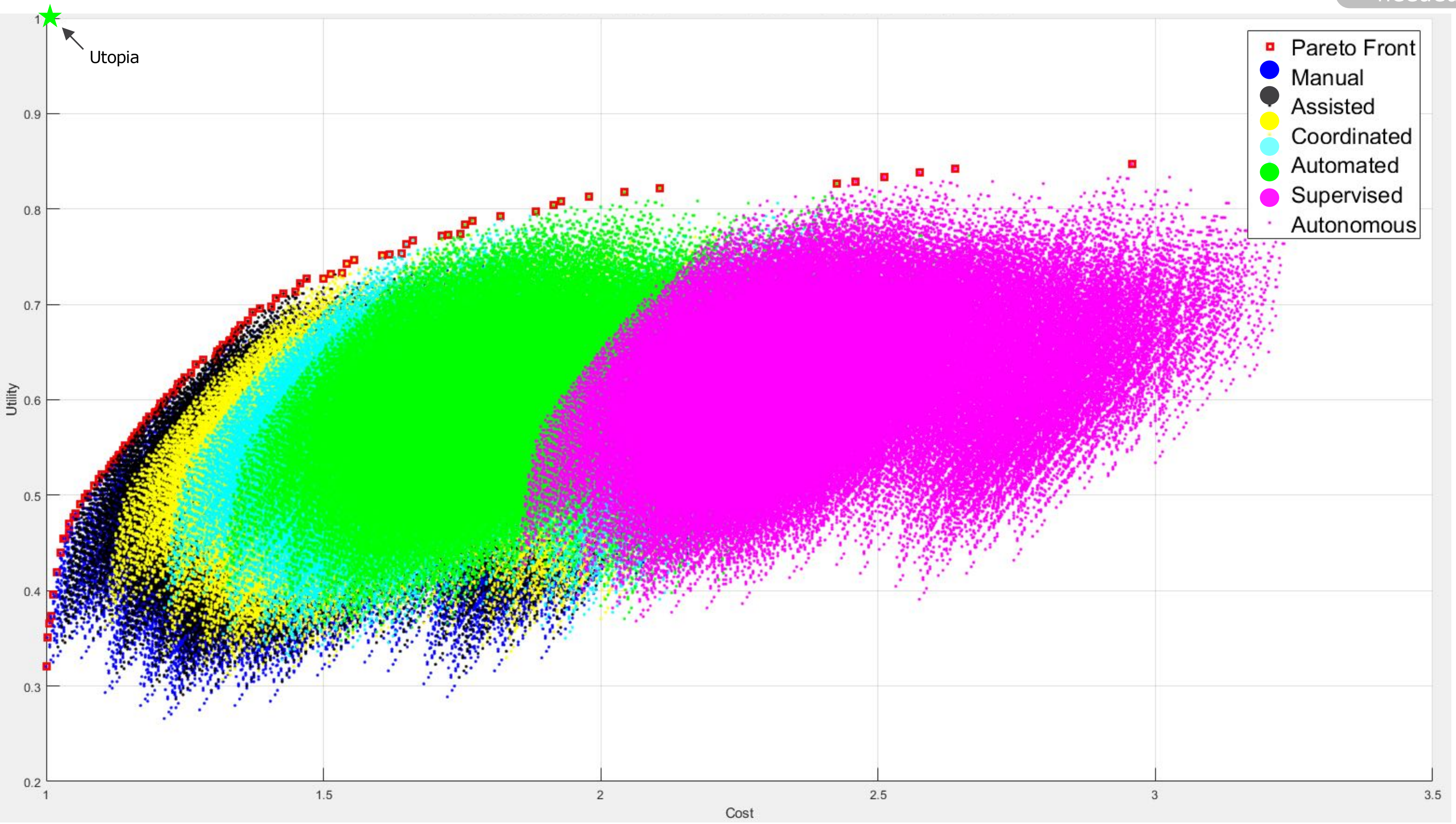
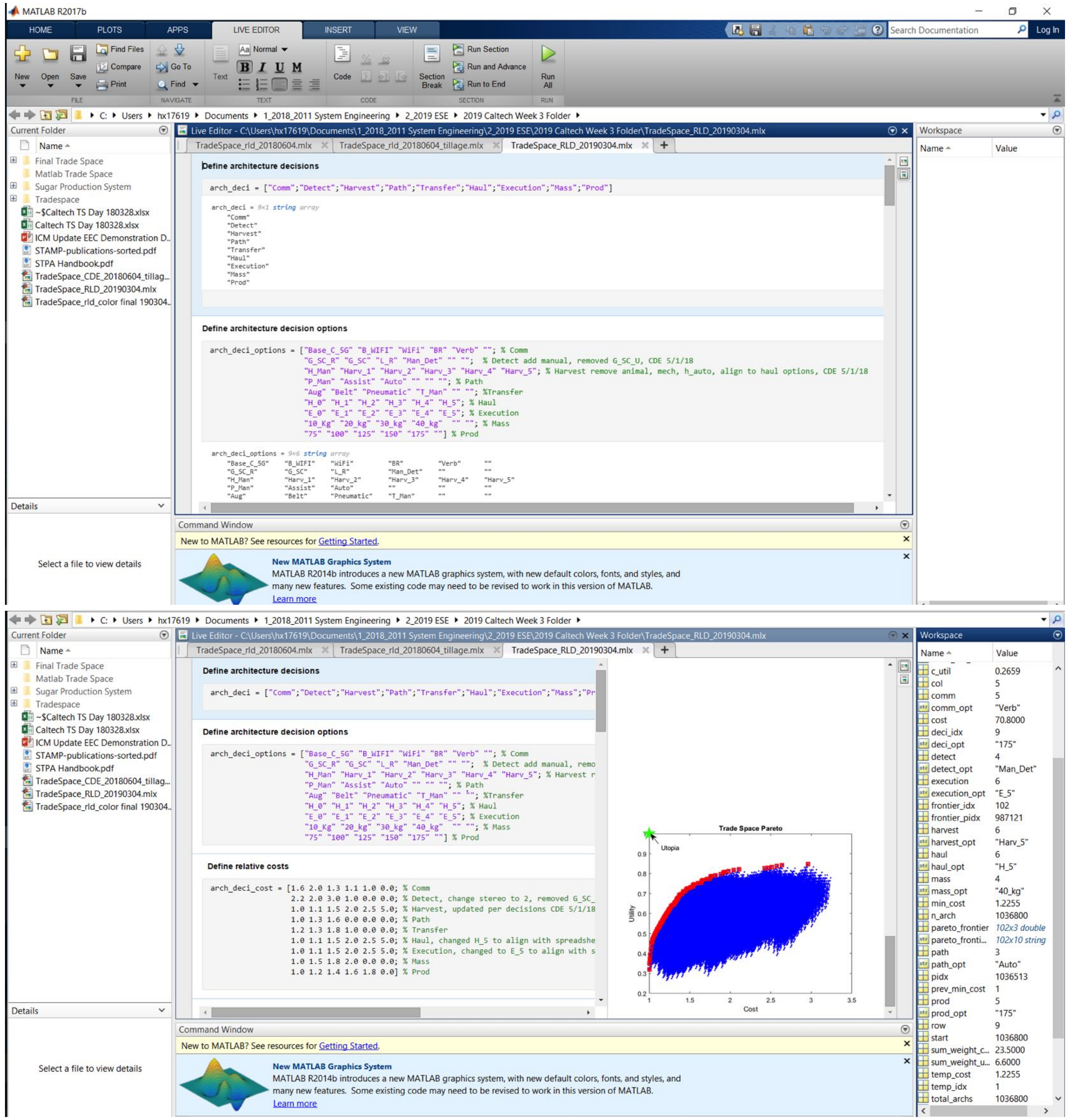
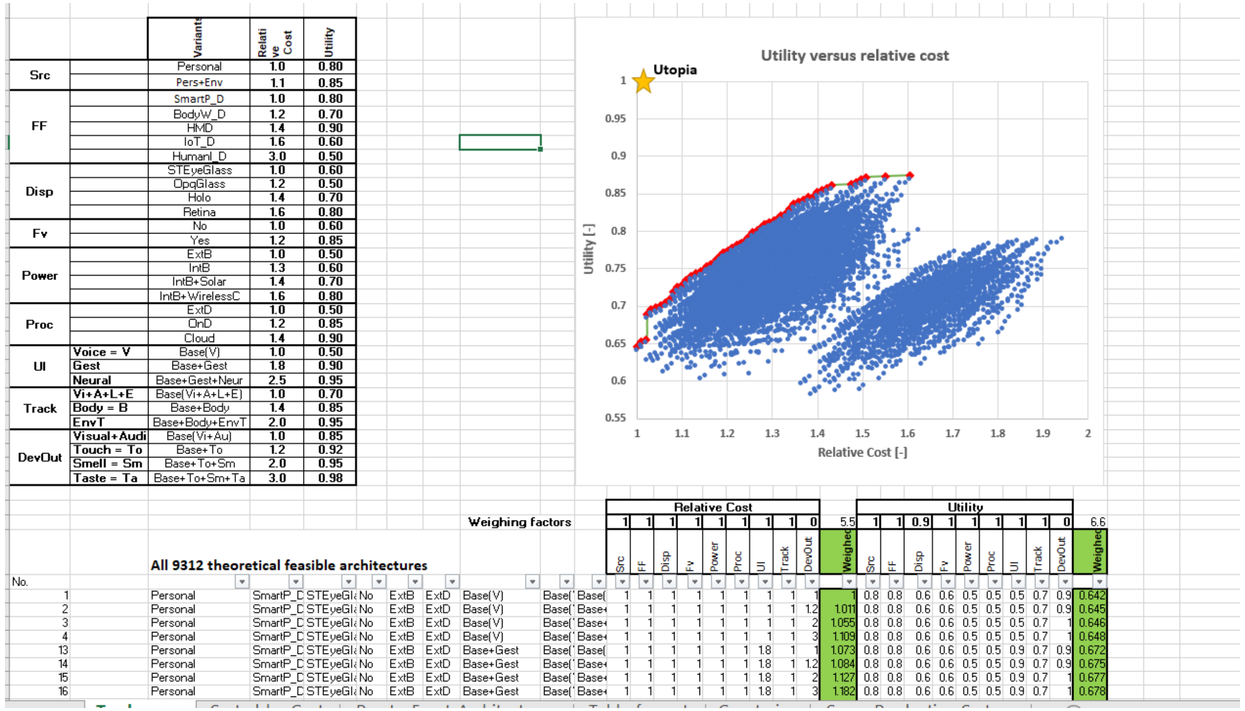
Arch. Option (Function Based) → What are comparison parameters? → Assess Relative Cost Within function → Assess Relative Utility Importance → Assess Utility Perf. Parameters → **Evaluate Combinations** → Filter Concepts as needed



MatLab or EXCEL





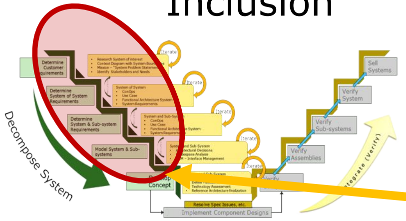
Arch. Option (Function Based) → What are comparison parameters? → Assess Relative Cost Within function → Assess Relative Utility Importance → Assess Cost Utility Across Functions → Evaluate Combinations → Filter Concepts as needed → Determine Optimal Solutions

Proposed Functional Concept

ID	Architectural Decision	Option 1	Option 2	Option 3	Option 4	Option 5	Option 6	Classification	Notes
Plan	Planning (Path)	Manual	Assisted	Automated				Function	
Comm	Communicating (State)	Verbal	Base: Cloud + 4G/5G	Base + WiFi	WiFi (M2M only)	Bluetooth (M2M only)		Form	Communicating machine state and machine location
Detect	Avoiding (Obstacles)	Manual	GPS/RTK + Stereo Cameras	GPS/RTK + Stereo Cameras + Radar	Lidar + Radar			Function	Obstacle avoidance for harvester and haulage unit
Navigate	Navigating (Path)	Manual	Assisted	Coordinated	Automated	Supervised	Autonomous	Function	Navigating planned paths for harvester and haulage unit
Harvest	Gathering (Plants)	Manual	Assisted	Coordinated	Automated	Supervised	Autonomous	Function	Gathering, cutting and cleaning processes of harvester
Transfer	Transferring (Commodity)	Shovel	Auger	Belt	Air			Form	Moving material from harvester to haulage unit
Haul	Hauling (Commodity)	Manual	Assisted	Coordinated	Automated	Supervised	Autonomous	Function	Aligning, receiving and unloading commodity
Prod	Productivity (Harvester)	AA t/hr	AA*1.15 t/hr	AA*1.25 t/hr	AA*1.50 t/hr	AA*1.75 t/hr			Small machine AA t/hr, large machine AA*1.75 t/hr
Mass	Weight (Harvester)	10,000	20,000	30,000	40,000			Form	19,262 kg Grain 19,500 kg Cane 30,000 kg Cotton

What does it mean to us?

Mission Inclusion



OPM Application

Arch. Option (Function Based)

What are comparison parameters?

Assess Relative Cost Within function

Assess Relative Utility Importance

Assess Utility Perf. Parameters

Evaluate Combinations

Extract Pareto Front

Filter Concepts as needed

Ex.

- **Cost**
- **Investment**
- **Price**
- **Risk**
- **Etc.**

- **Additional Insights**
- **Function**
- **Many More**
- **Need Rationale**

Determine Optimal Solutions

SysML Application

Why is this Useful?

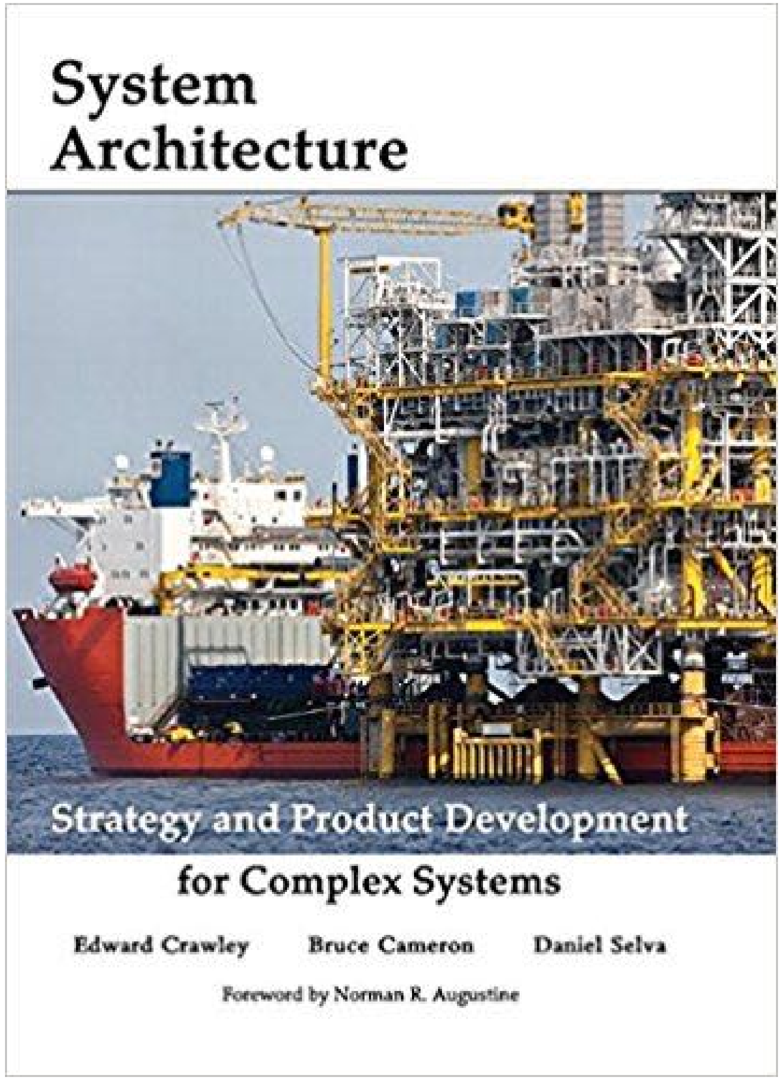
- Demonstrates that the different languages can be used together in a single tool
  - Alternative would be to create the OPM model in OPCAT use printout as a basis for traceability
  - The integrated approach means that true impact analysis and traceability can be done.
- An OPM Model can created as a starting point with SysML used to refine the concepts
  - The elements were then used to create the SysML diagrams
  - Some additions and changes were needed
  - Alternative would be to create separate OPM and SysML models and create trace links between them
- Other concepts can be added such as parametrics, executable state machines, traceability to requirements, analysis and PLM tools, etc.

Conclusions

- Many of the concepts in OPM can be duplicated in a SysML tool
  - There is some cognitive dissonance
  - Provide an alternative means of looking at a system
  - Provide a starting point for people familiar with OPM
  - Both are useful
- The models demonstrate that the languages can be used together
  - OPM as a starting point can be used to develop a detailed SysML model
- More work and research are needed
  - ALL OPM concepts were not added as this was more of a proof of concept than a solution.
  - The text portion of OPM (OPL) was not implemented.
  - "Finally, defining a hybrid methodology exploiting the advantages of the two languages seems to be a challenging issue." *Systems Modeling Languages: OPM Versus SysML*

Acknowledgement and thanks

- Examples were taken from the Edward Crawley et al Book System Architecture: Strategy and Product Development for Complex Systems
- MIT SDM course slides
- John Deere for their support
- Tutorials and papers by Dov Dori



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Thank You!

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