SYSTEMS OF THE FUTURE : MODELS OF THE FUTURE

("COMMERCIAL AND CONSUMER PRODUCTS VIEW OF MBSE")

AUTHOR: BRUCE BEIHOFF, WHIRLPOOL CORPORATION
CONTRIBUTORS WHIRLPOOL:
DENNIS KEHL
GREG GARSTECKI
BRENNER SHARP
FARSHAD FARID
SANT RANJAN

2011 FRONTIERS IN MODEL-BASED SYSTEMS ENGINEERING
"GEORGIA TECH LEARNING CENTER"
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engineering & technology

OUTLINE:

THE PRESENTATION:

- THE PURPOSE : What will I be talking about
- THE PREMISE :"Why Model Based Systems Engineering"
- THE PRIZE : "What's the payback"
- THE LEAN : " The effect of LEAN on System Modeling"
- THE PICTURE :" How does it look inside Whirlpool" Gallery of Examples
- THE PROPOSAL: "Where do we go from here"

THE PURPOSE

- Explain the “Consumer/ Commercial Application Evolution” and It’s drivers towards System Model Based Design.
- Recommend “Frontiers” of Model Based System Engineering…
- *Expose some of the challenges and opportunities we have encountered.*

THE PREMISE

- **The Vision of the Commercial/ Consumer /Home is Changing:**

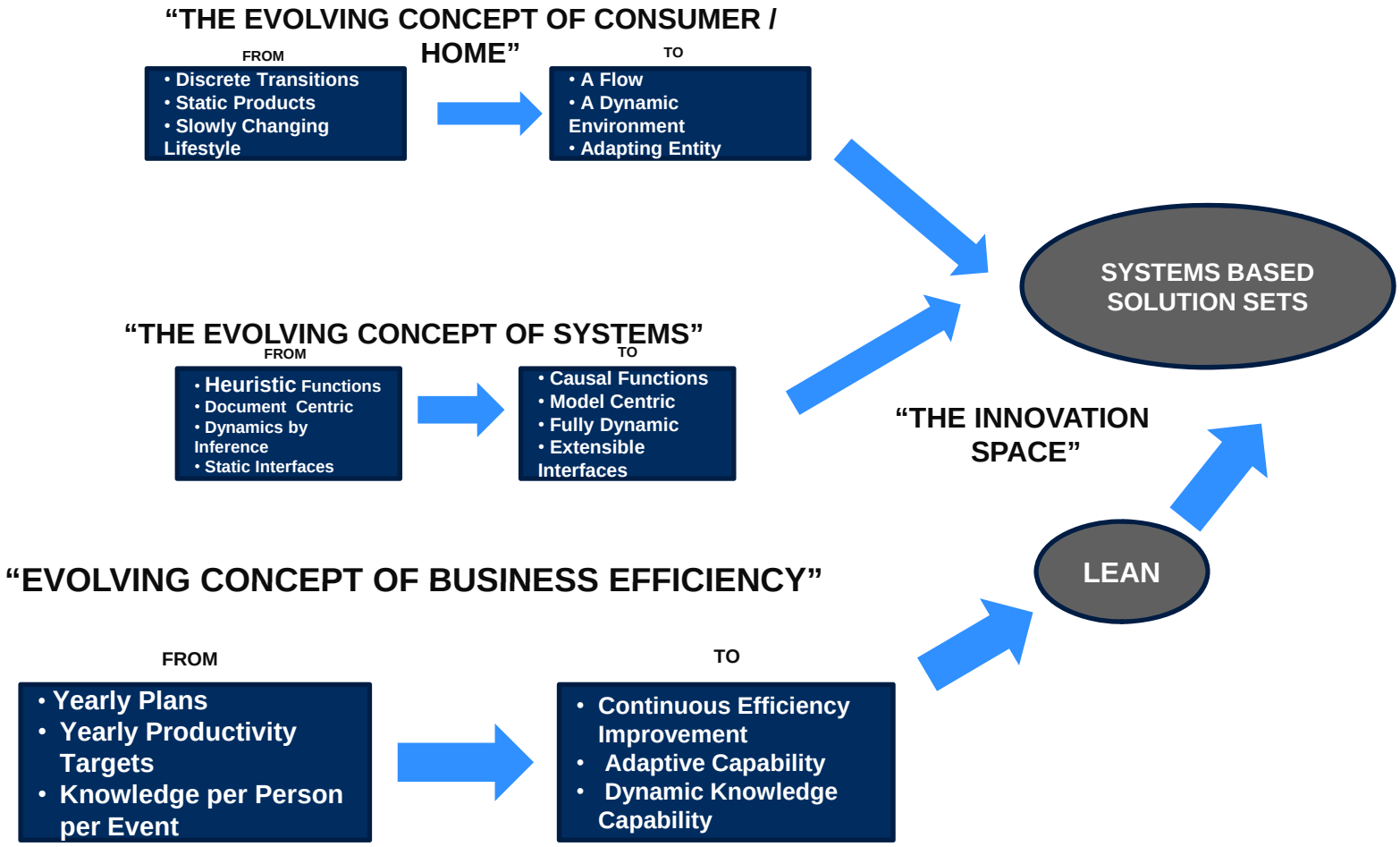
FROM	TO
• Discrete Transitions • A Static Products • Slowly Changing Lifestyle	• A Flow • An Dynamic Environment • Adapting Entity

- **The Vision of Systems is Changing:**

FROM	TO
• Heuristic Functions • Document Centric • Dynamics by Inference • Static Interfaces	• Causal Functions • Model Centric • Fully Dynamic • Extensible Interfaces

THE PREMISE 1 + …

Convergence of an Opportunity Space + Solution Space + Business Efficiency



THE PRIZE (Payback Opportunity and Drivers…)

- 1.5 Billion Homes
- 15 Million New Homes per Year
- 200 M Homes under renovation per Year
- People, Governments, Environments are redefining the Home/Consumer Space…
- Adjacent Spaces to home redefined : new trade offs and opportunities.
- Large Energy, Environmental, and Performance Benefits …
- High Production Rates with High Product Diversity …

- The rate of change of our markets increased 2-3x in 10 years
- Business efficiency demands increased 2-3x in 10 years

- **The only efficient way to deal with all of these factors has been system modeling.**

THE PRIZE: WHIRLPOOL PRODUCTIVITY THROUGH MBSE

How mathematical modeling can help reduce the optimization process time for 100 different models

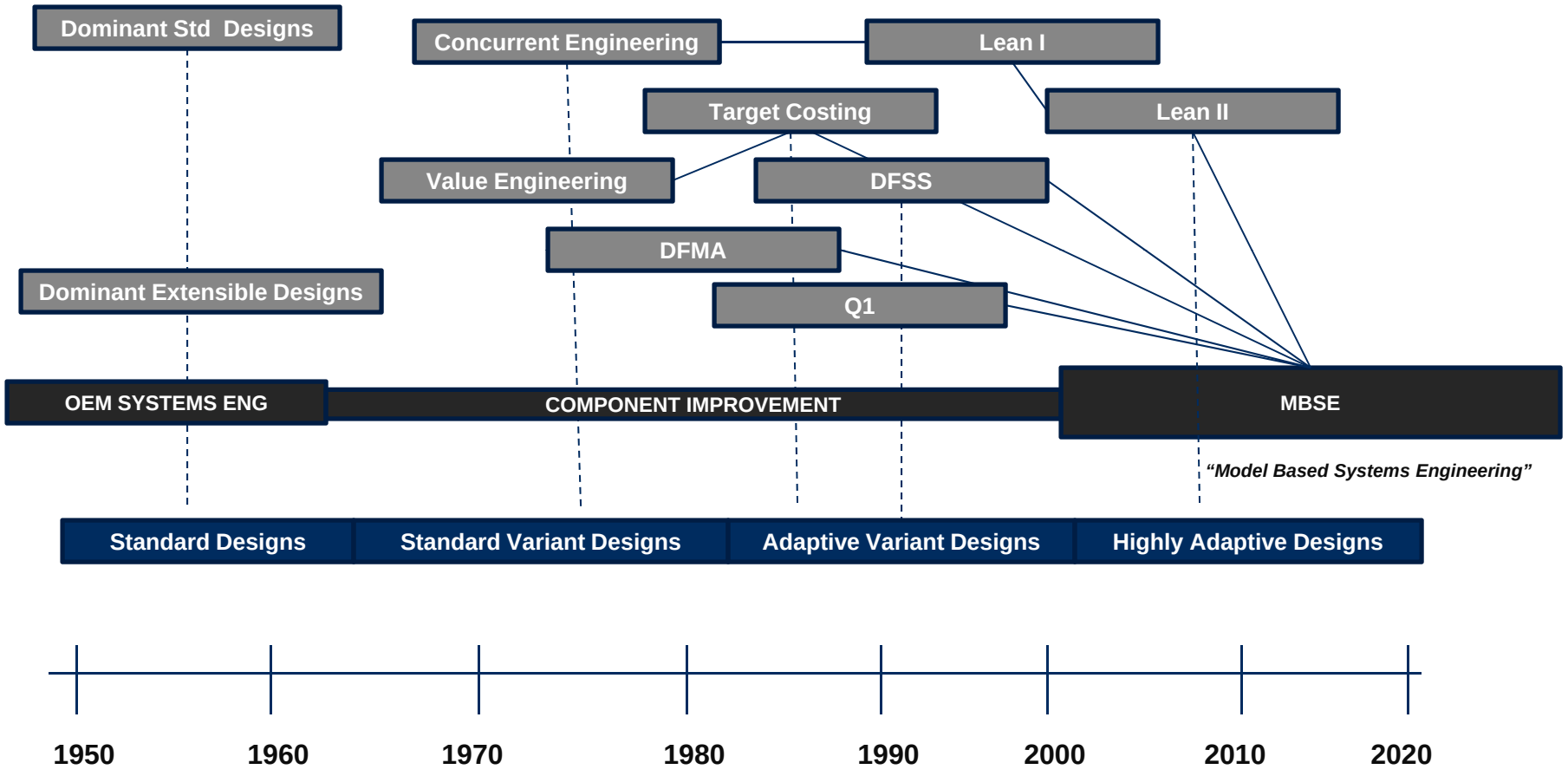
Tools	Process 1	Process 2
Mathematical modeling (time:100 models/day)	-	100 models (1/100days x 100)
CFD/Ansys (time:1 model in 2 days)	100 models (2days x 100)	10 models (2days x 10)
Actual (time:1 model in 5 days)	5 models (5days x 5)	2 models (5days x 2)
Time required (time:100 models)	225 days	31 days

Testing of 100 Models

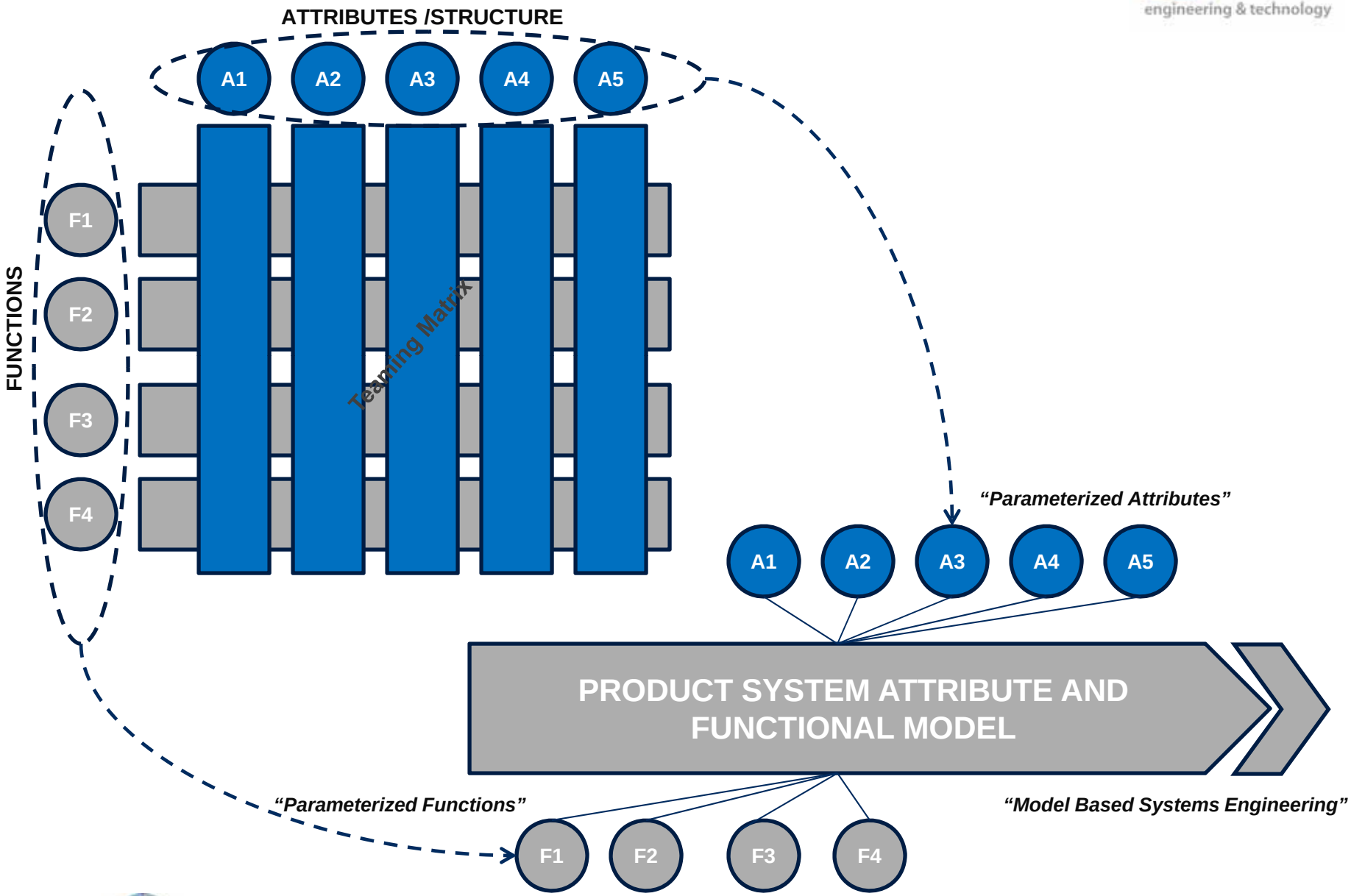
	Accuracy	Speed	Resources
Actual Testing	Excellent	Very slow	High
CFD/Ansys Simulation	Good	Slow	Less
Mathematical Modeling	Medium	High	Less

LEAN PRODUCT SYSTEM DEVELOPMENT TIMELINE

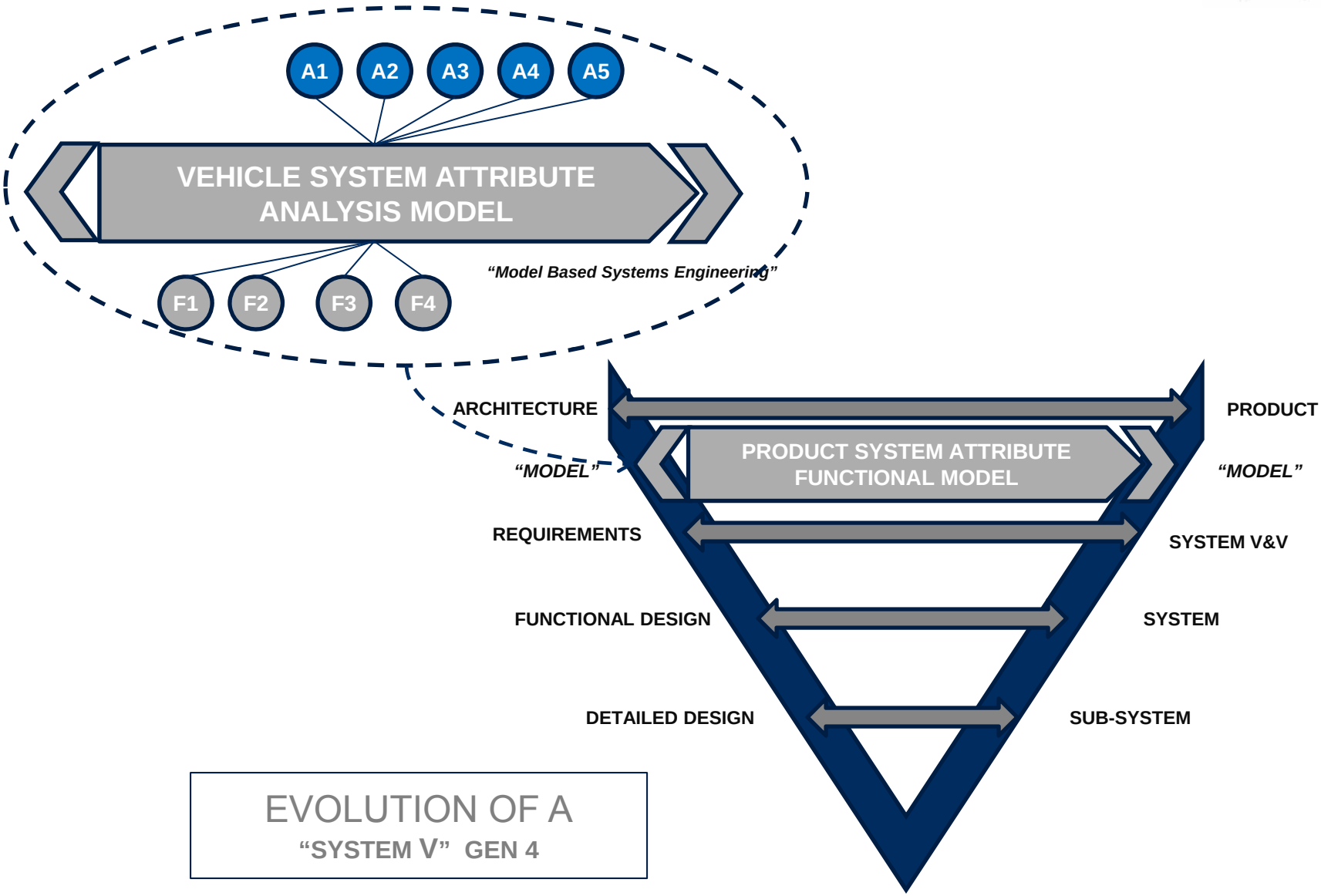
"THE PROLIFERATION OF INITIATIVES, THE COMING OF LEAN …"



LEAN PRODUCT DEVELOPMENT EVOLUTION

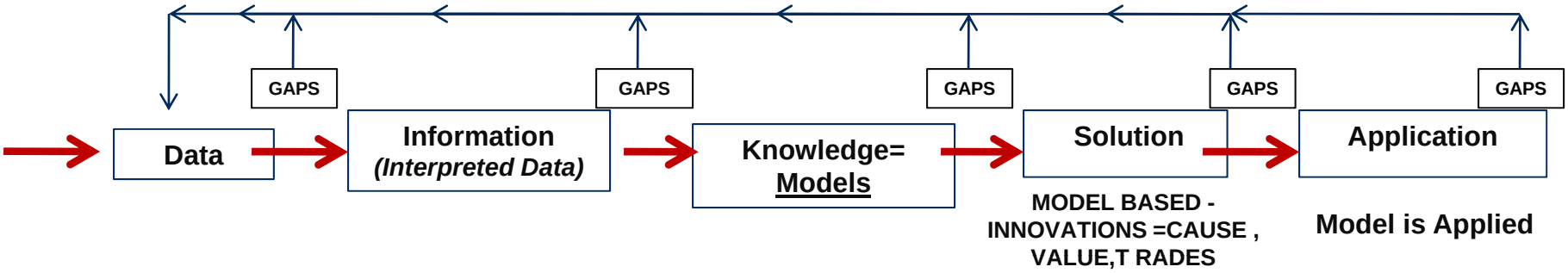


LEAN PRODUCT DEVELOPMENT EVOLUTION



EVOLUTION OF A
"SYSTEM V" GEN 4

LEAN=KNOWLEDGE=MODEL BASED



Observations
Resolution
Accuracy
Rate
Focus

Trends
Patterns
Structure

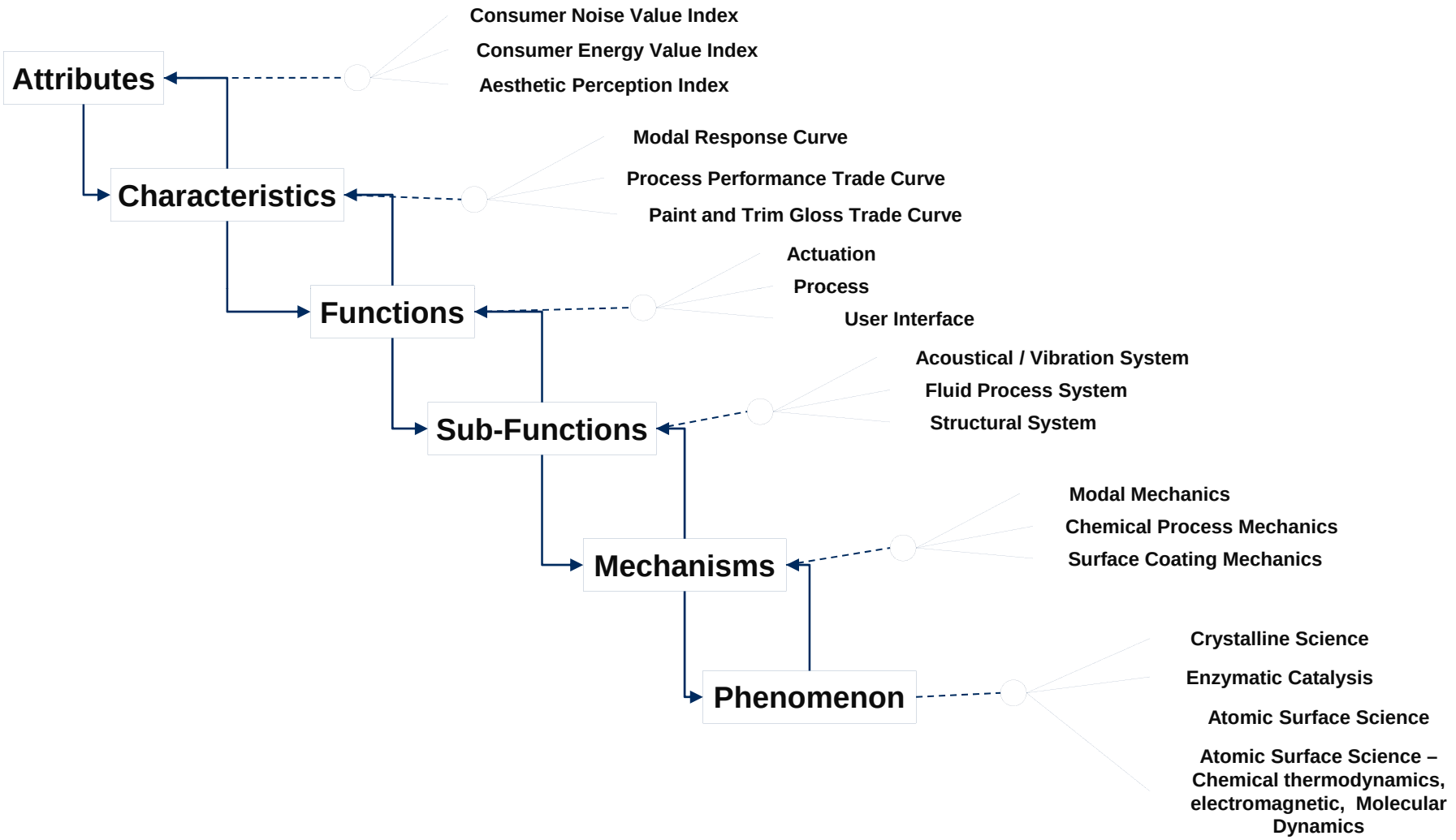
CAUSE and EFFECT
DYNAMICS
LIMITS
DIMENSIONS
DOMAINS
TRADE SPACE

Design Option A
Design Option B
Design Option C
Design Option Xn

Multiple options evaluated **Design Selected**

LEAN = 5 WHY'S= CAUSALITY= SYSTEM MODELS

{EXAMPLES}



LEVELS OF MODELING FOR PRODUCT DEVELOPMENT

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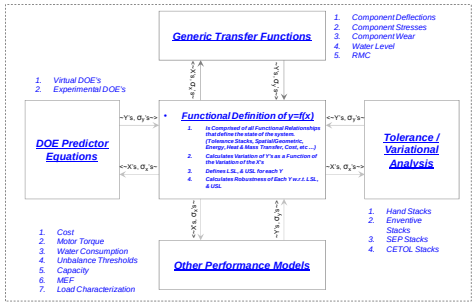
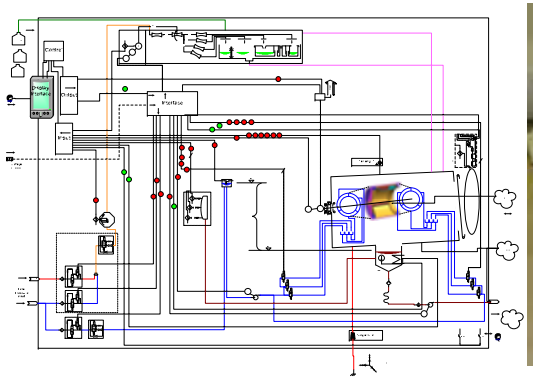
Greater System Development Capability

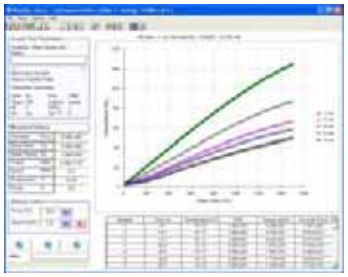
		Model Type	Knowledge Classification	Translation (Example)	Predictability	Transport -ability	Stewardship	Continuous Improvement
Mental Models	1	**Individual Experts**	Models in Individual Minds. Understanding based on single use cases.	An expert in VA Wash Performance	Varies Greatly	Dependent on Retention of Key experts	Independent Experts Personal Dynamics	
	2	**Expert Led Group Events**	Event by Event interpreted solution case understanding	Community of Expert practice in VA wash performance	Varies Greatly	Dependent on Retention of Key experts	Independent Experts & Community Dynamics	Sporadic Crisis Driven Update Cycles
	3	**Distributed Expert Design Guides and Rule Sets (i.e., Subsystem Design Specification)**	Historical Design Case Generalized rule Understanding	Community of Expert Practice + Design Guides ; Req. Specs	Improving over long cycles	Dependent on Retention of Key experts	Distributed Experts Group	Long Document Update Driven Cycles
Physical and Virtual Models	4	**Boundary Response Mathematics— Empirical Data Generated**	Black Box Response Fit Understanding	Community of Practice + Design Guide+ OPEX black box model	Medium length cycles of improvement	Dependent on Maintenance of Model Base	Distributed Experts Group and Knowledge Base	Dependent on lab test and interpretation cycles
	5	**Dynamic Functional Mathematics**	Functional Boundary Understanding	Community of practice that drives knowledge by causal models	Constantly Improving over more rapid cycles	Dependent on Maintenance of Model Base	Constantly Developing Expert Knowledge Base	Continuous update cycles shorten as models improve.
	6	**Dynamic Mechanistic Mathematics**	Deep Physical Understanding	Community of practice that drives knowledge by deep models	Constantly Improving over shortest cycles	Dependent on Maintenance of Model Base	Constantly Developing Expert Knowledge Base	Continuous update cycles shorten as models improve

EXAMPLES OF PHYSICAL AND VIRTUAL MODELS

VIRTUAL MODEL







$$\Delta p = \gamma\left(\frac{1}{R_x} + \frac{1}{R_y}\right)$$

PHYSICAL MODEL

Model Type	Knowledge Classification
Individual Experts	Models in Individual Minds. Understanding based on single use cases.
Expert Led Group Events	Event by Event interpreted solution case understanding
Distributed Expert Design Guides and Rule Sets (i.e., Subsystem Design Specification)	Historical Design Case Generalized rule Understanding
Boundary Response Mathematics— Empirical Data Generated	Black Box Response Fit Understanding
Dynamic Functional Mathematics	Functional Boundary Understanding
Dynamic Mechanistic Mathematics	Deep Physical Understanding

Greater System Development Capability

Mental Models

Physical and Virtual Models

THE PICTURE :WHERE IS HOME/COMMERCIAL "MBSE" TODAY at WHIRLPOOL ….

- Systems Models Consumer / Commercial Environment
  - We have adopted MBSE "as part of " Transformational change
  - Working to add dimensions and domains

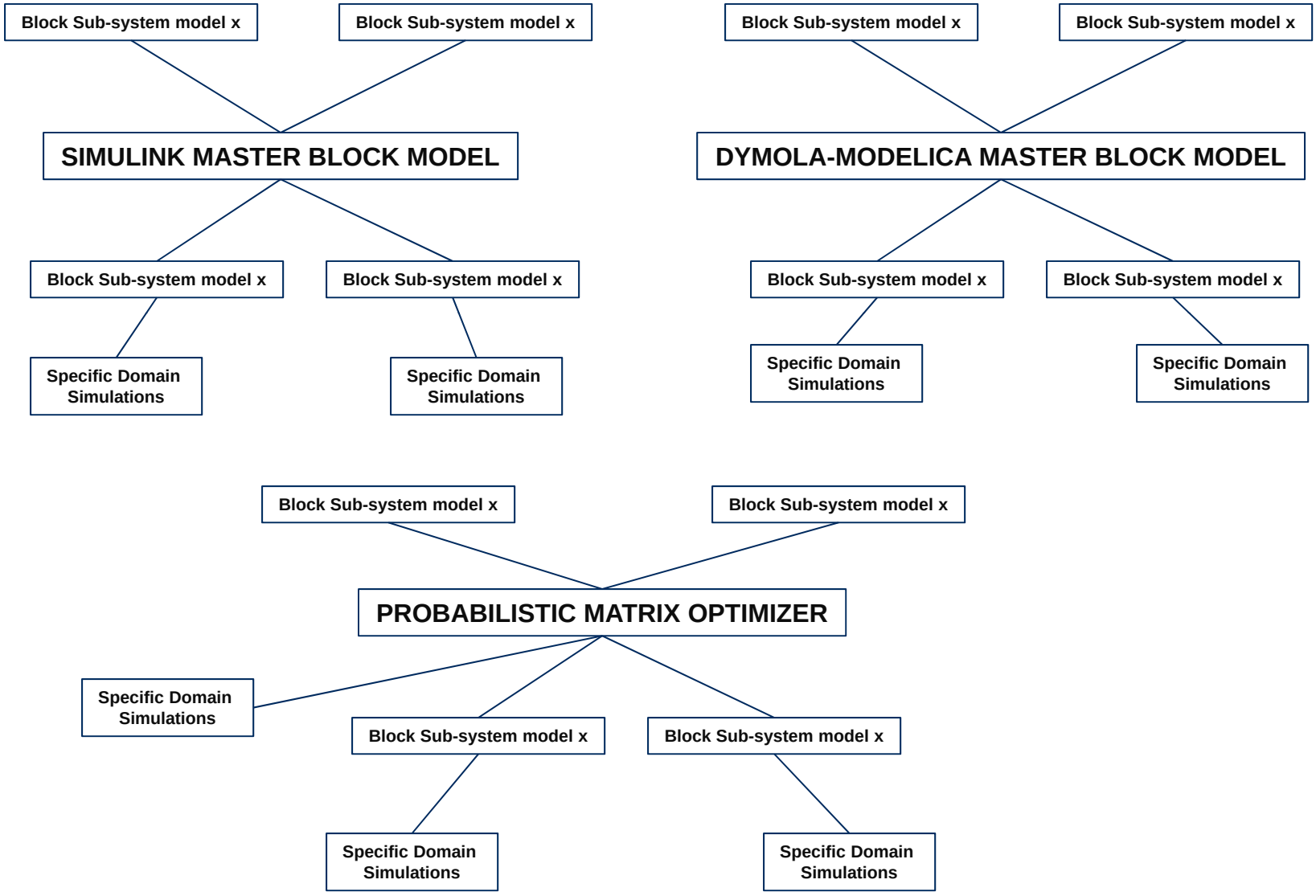
- Systems Methods and Initiatives (Lean + Others)
  - Attempting to Coordinate using MBSE …
  - Need to Learn form Other Applications/Industries

- The commercial and home/consumer environment under-studied compared to other systems …
  - Opportunity to expand MBSE into/ Applied Science focused on commercial applications / home / global high volume production

THE PICTURE CONTINUED

NARRATIVE GALLERY OF WHIRLPOOL EXAMPLES

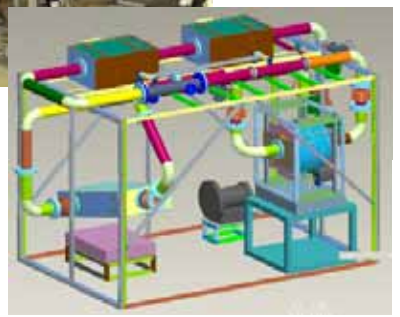
MODEL MAPS AT WHIRLPOOL



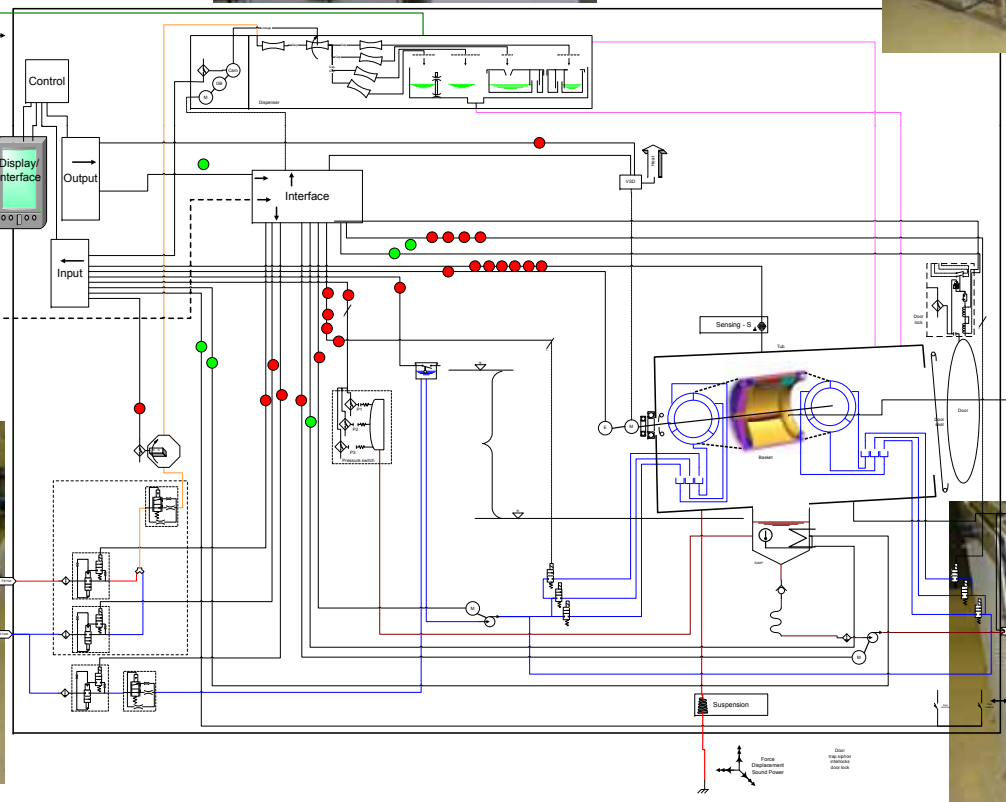
Understanding the System & Process : System Model Test Beds

WASHING

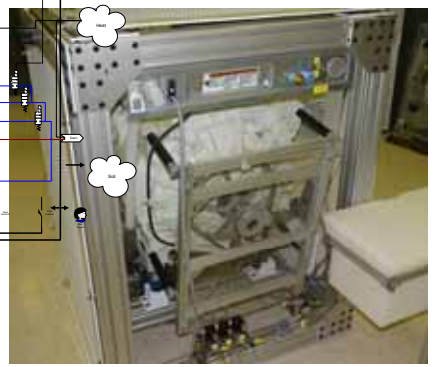
COOLING



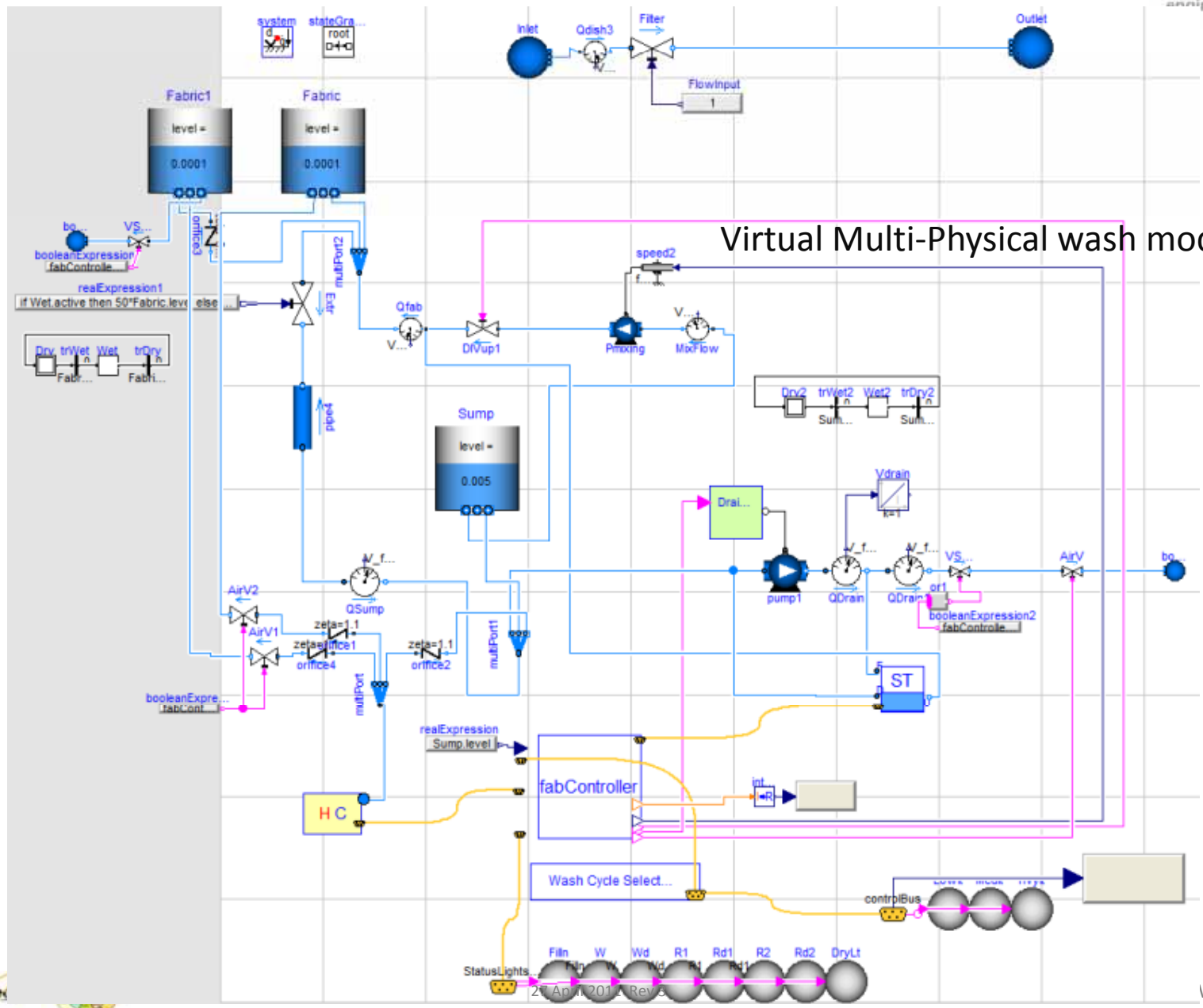
SYSTEM DYNAMICS



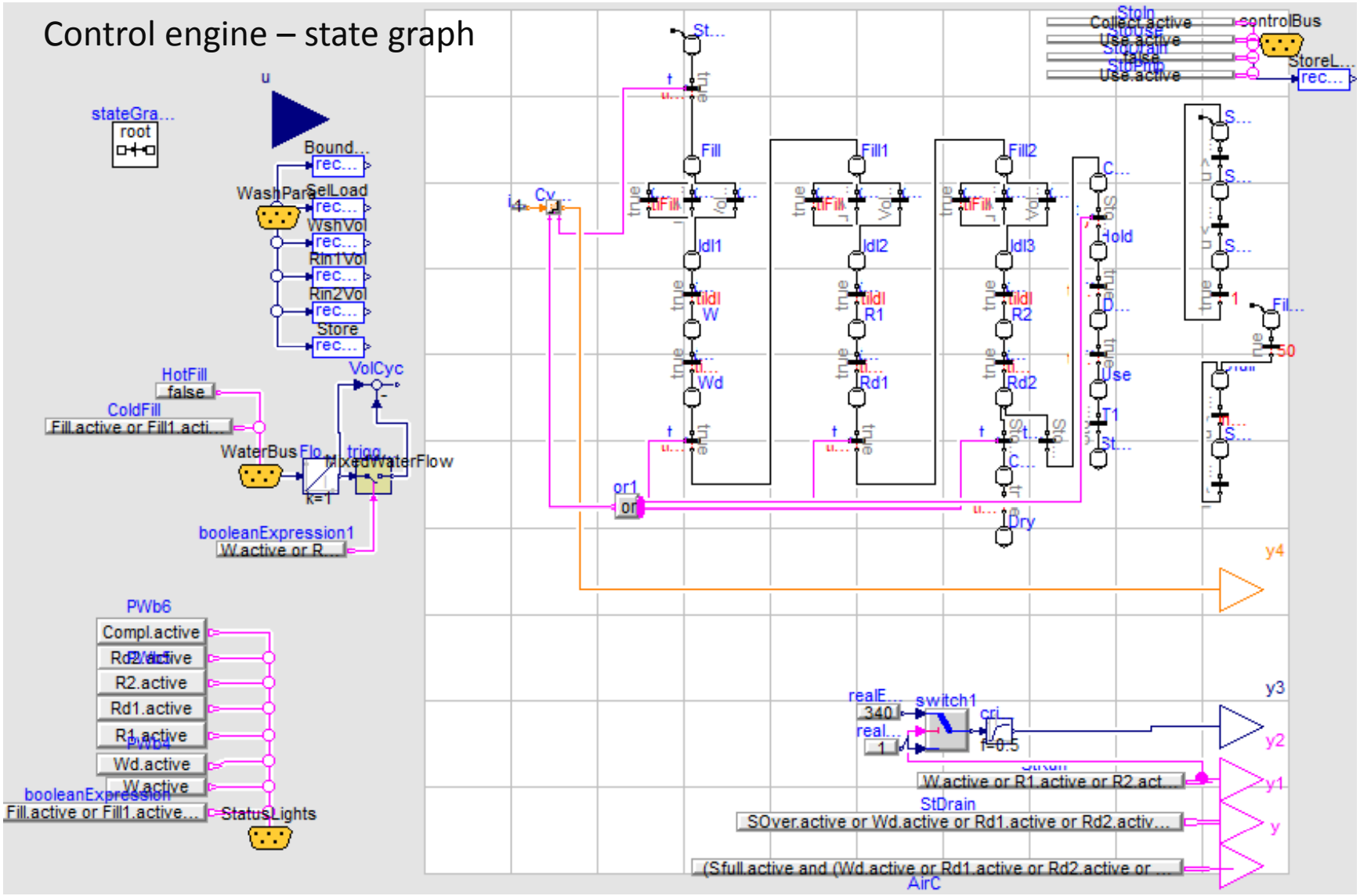
DRYING



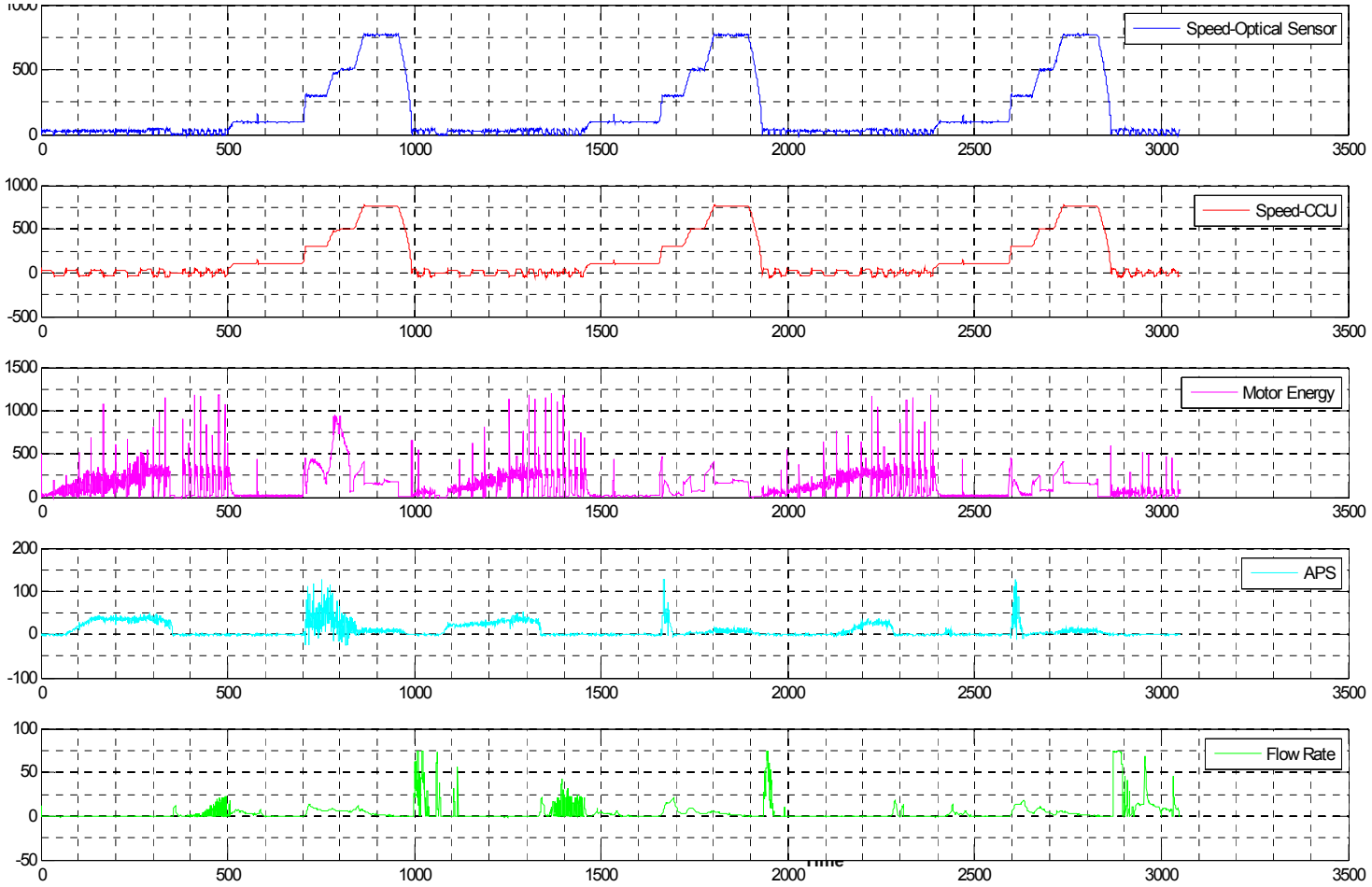
Understanding the System & Process - Virtual Multi-Physical Wash Model



Control engine – state graph

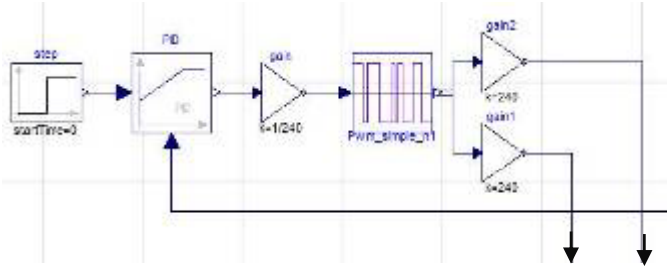


Understanding the System & Process Cycle Outputs – Ultra-Low Resource Cycle

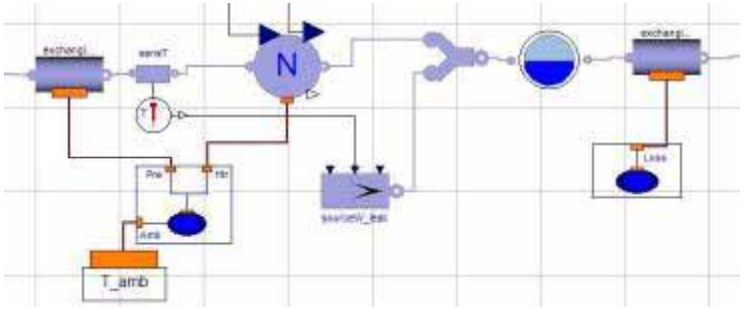


Wash **Rinse 1** **Rinse 2**

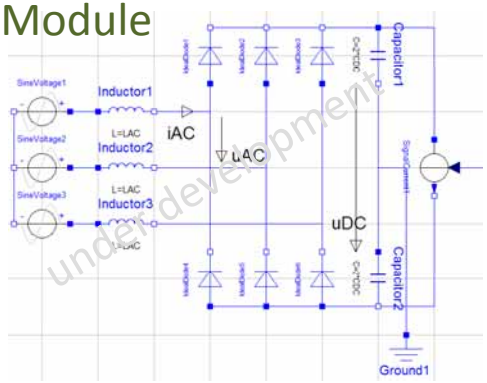
Process /Control Module



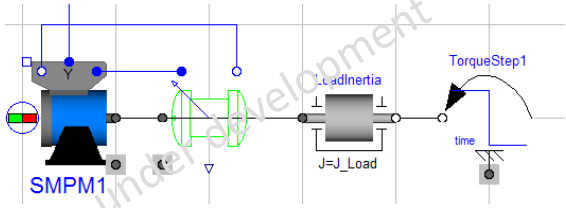
Thermodynamic Module



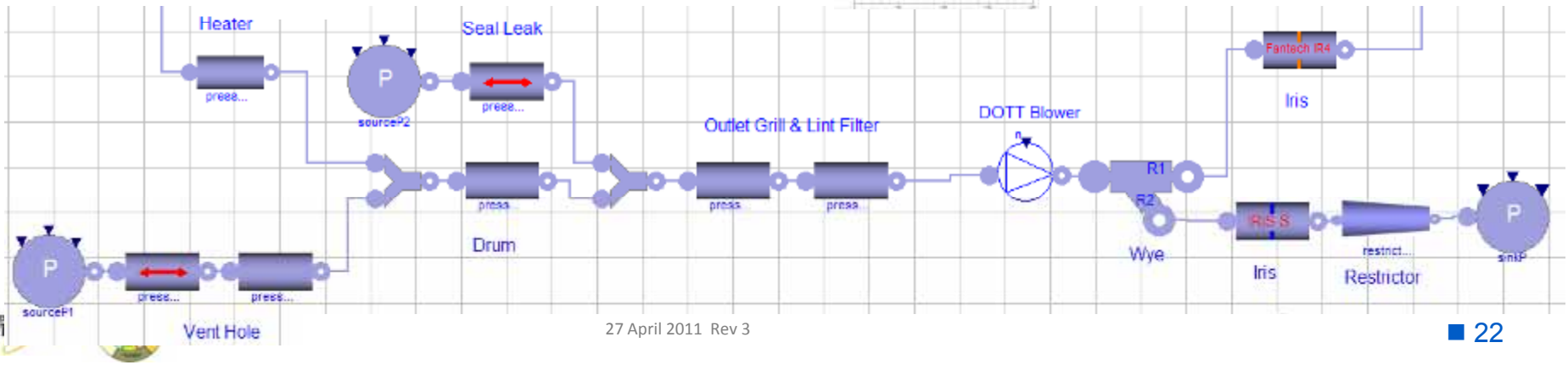
Electronic Module



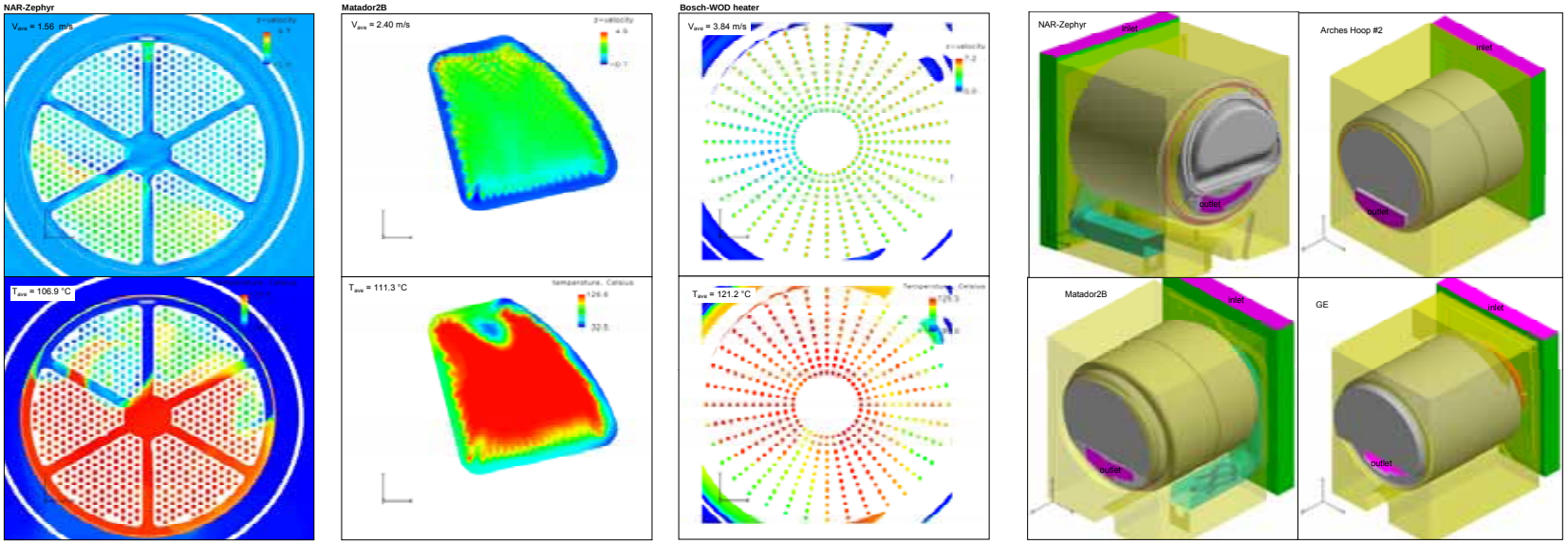
Drum/Drives Module



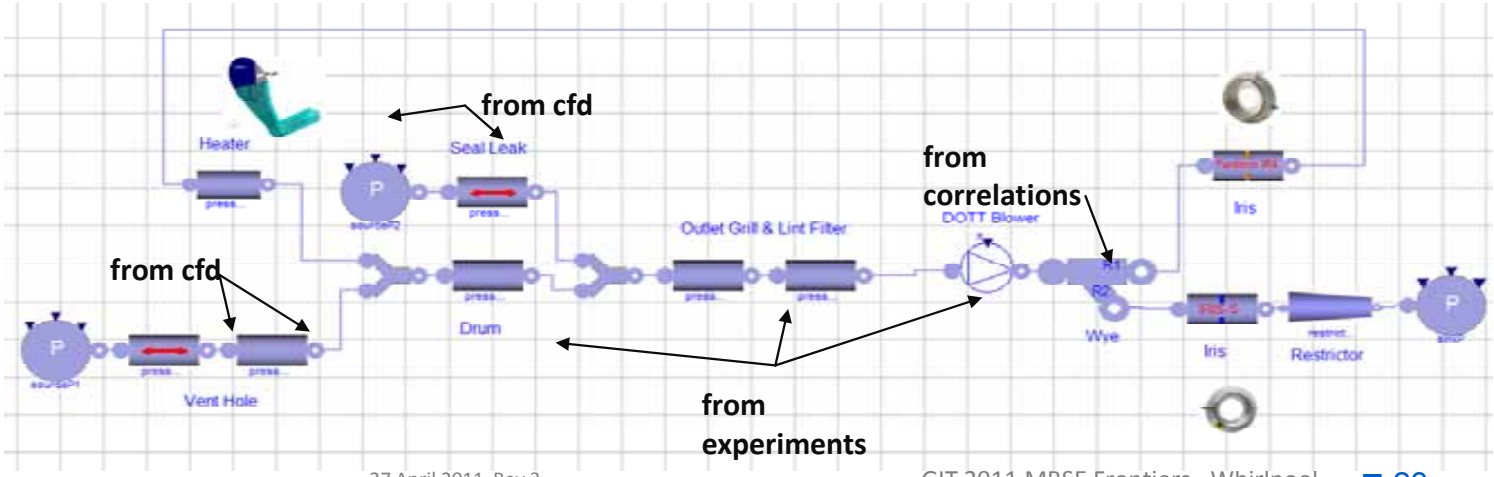
Fluids Module



Understanding the System & Process – Flow System Sub-Model

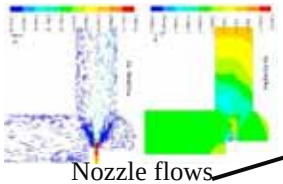


Flow system model with input from CFD, experiment, & literature

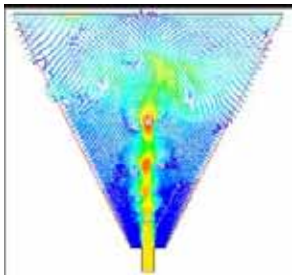


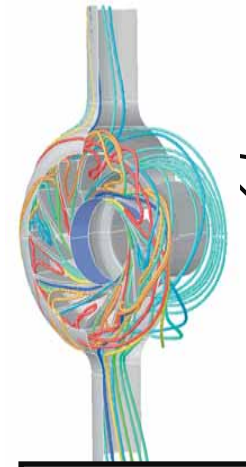
PRODUCT LEVEL MULTI-DIMENSION MODELS ARE HAPPENING …

…..”BUT THEY NEED EXTENSION AS COMPLEXITY INCREASES” …



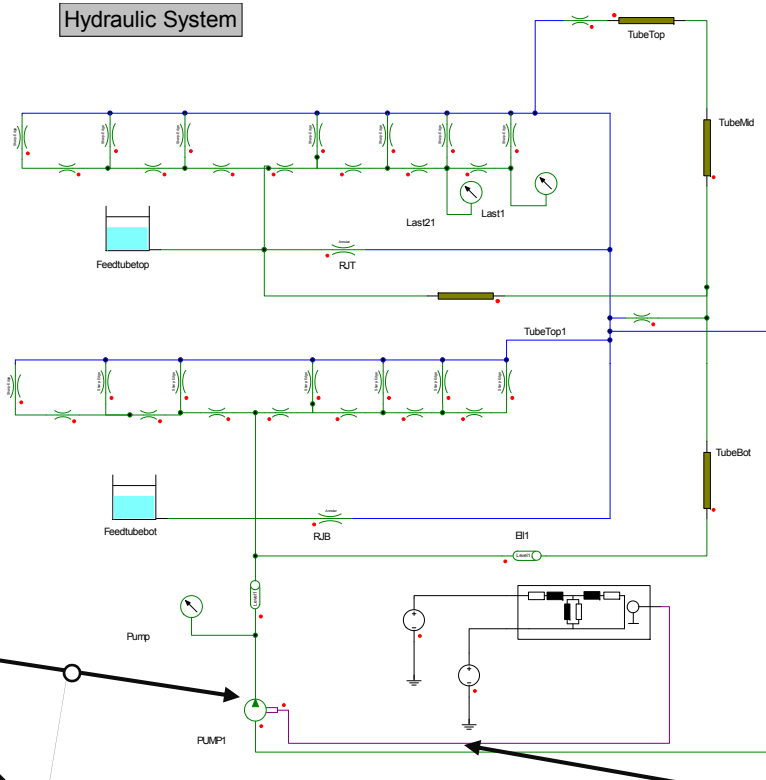
Nozzle flows

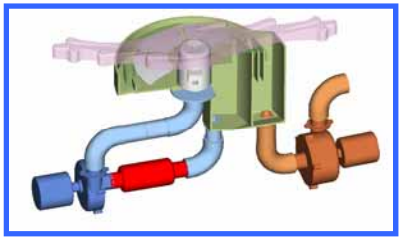




Function
Mechanism
Phenomenon

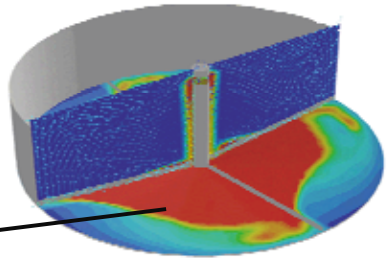
Hydraulic System



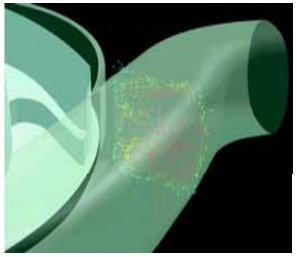


Wash system concepts

Sump interactions



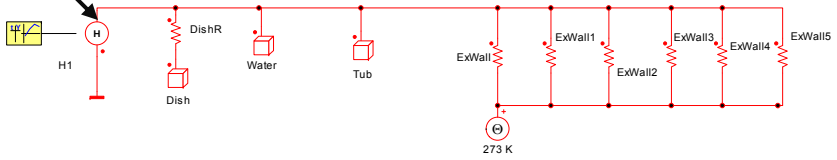
Optimizing pump/plumbing



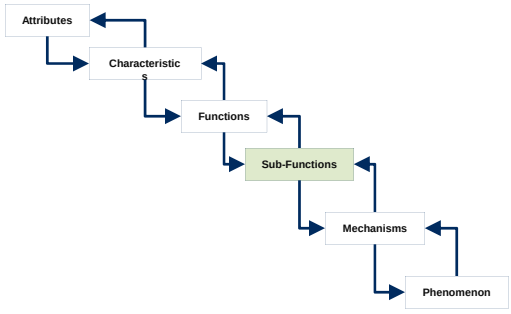
$$I = \int_S \mathbf{J} \cdot d\mathbf{a} = -\frac{\partial}{\partial t} \int_V \rho \, dV,$$

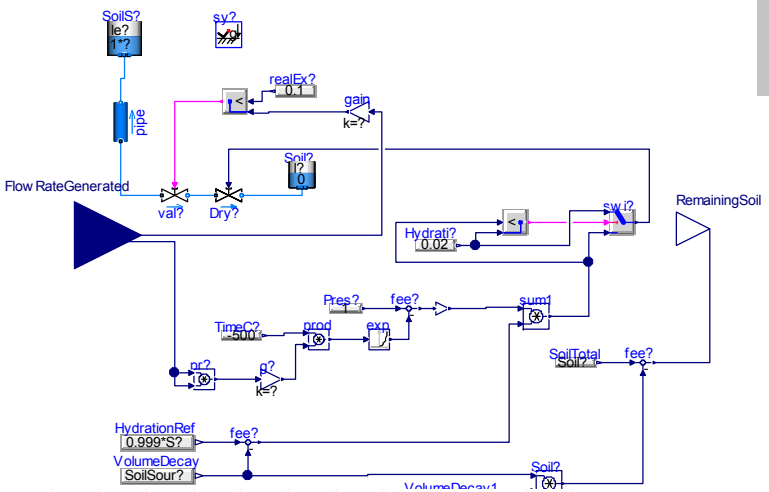
$$\int_S \rho \mathbf{u} \cdot d\mathbf{a} = -\int_V \nabla \cdot (\rho \mathbf{u}) \, dV,$$

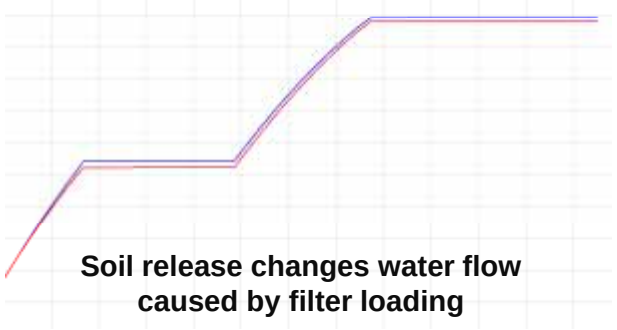
Thermal System



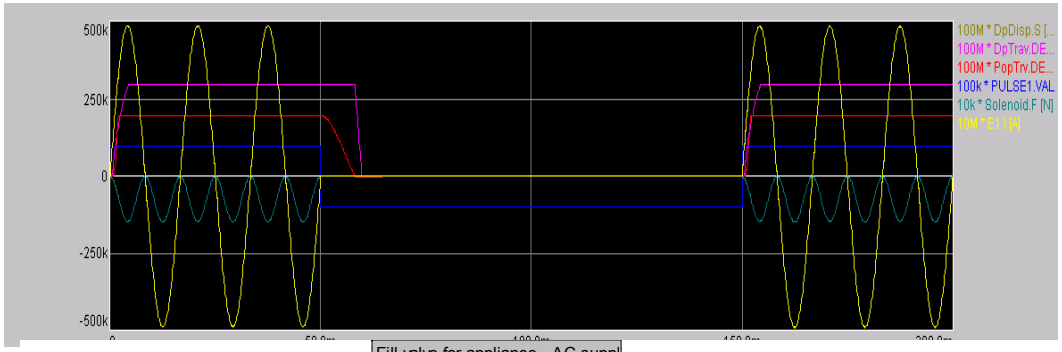
DYNAMIC HYBRID PROCESS MODEL STOCHASTIC BLOCKS



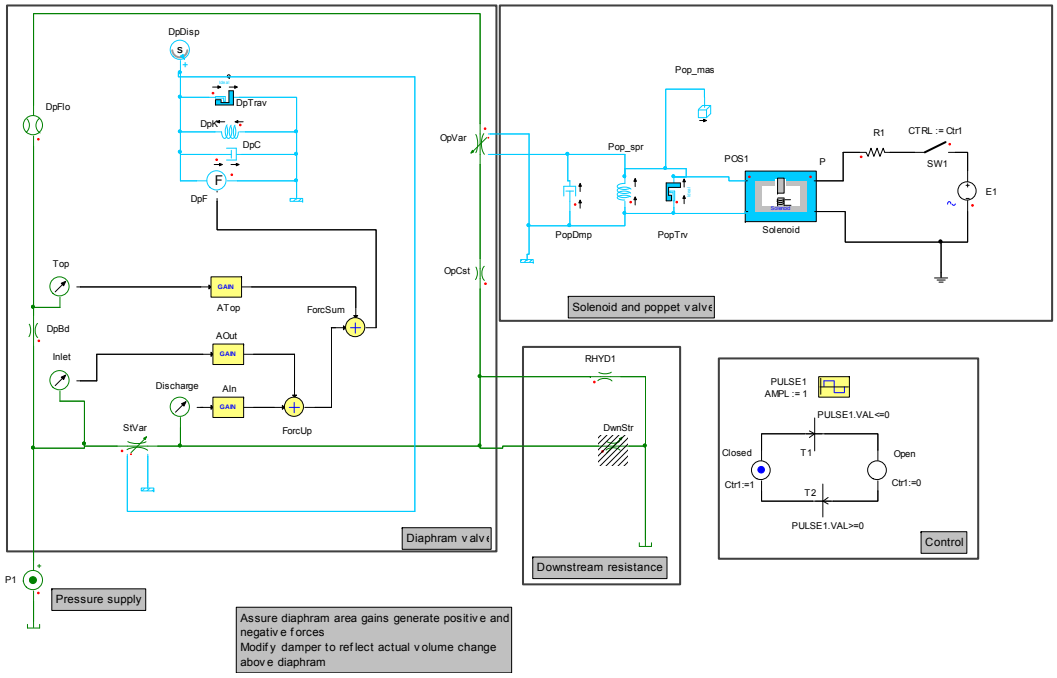




Soil release changes water flow caused by filter loading

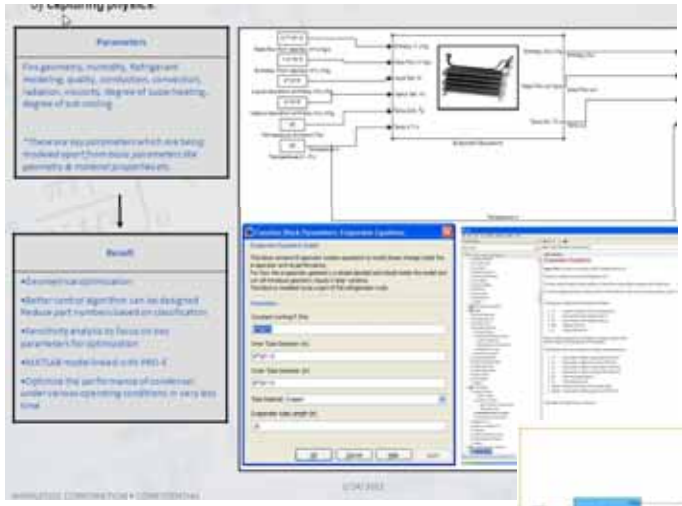


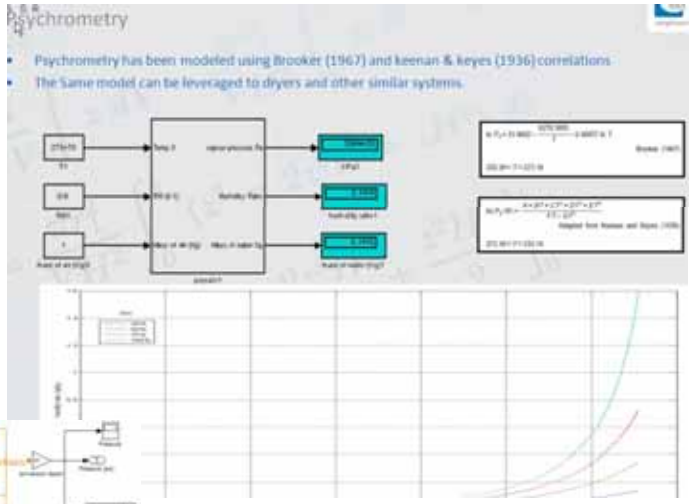
Fill valve for appliance - AC suppl

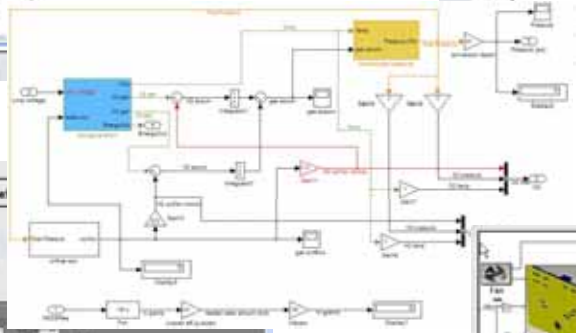


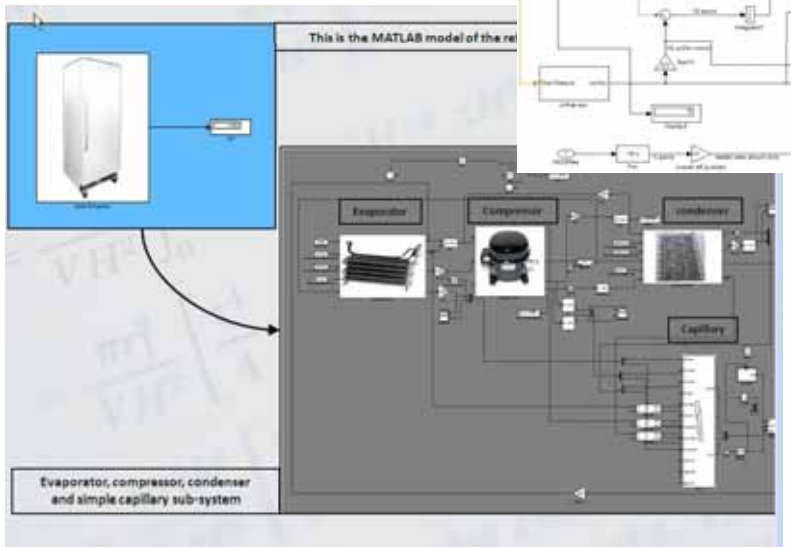
Assure diaphram area gains generate positive and negative forces
Modify damper to reflect actual volume change above diaphram

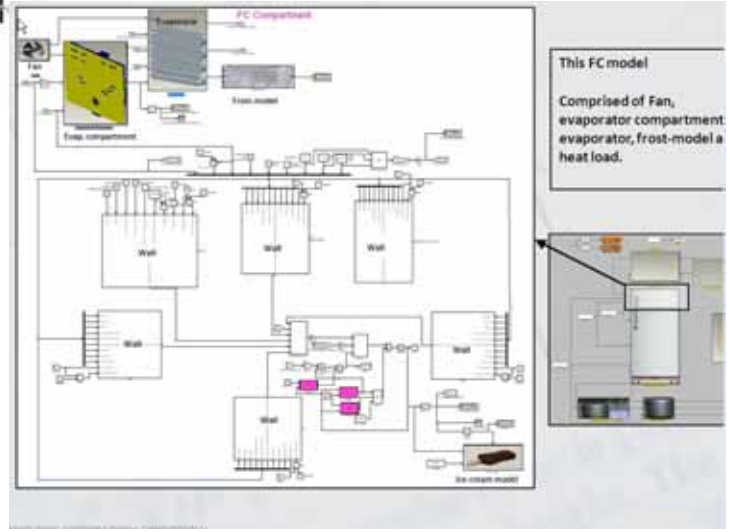
FUNCTIONALIZED DYNAMIC MASTER MODEL SIMULINK



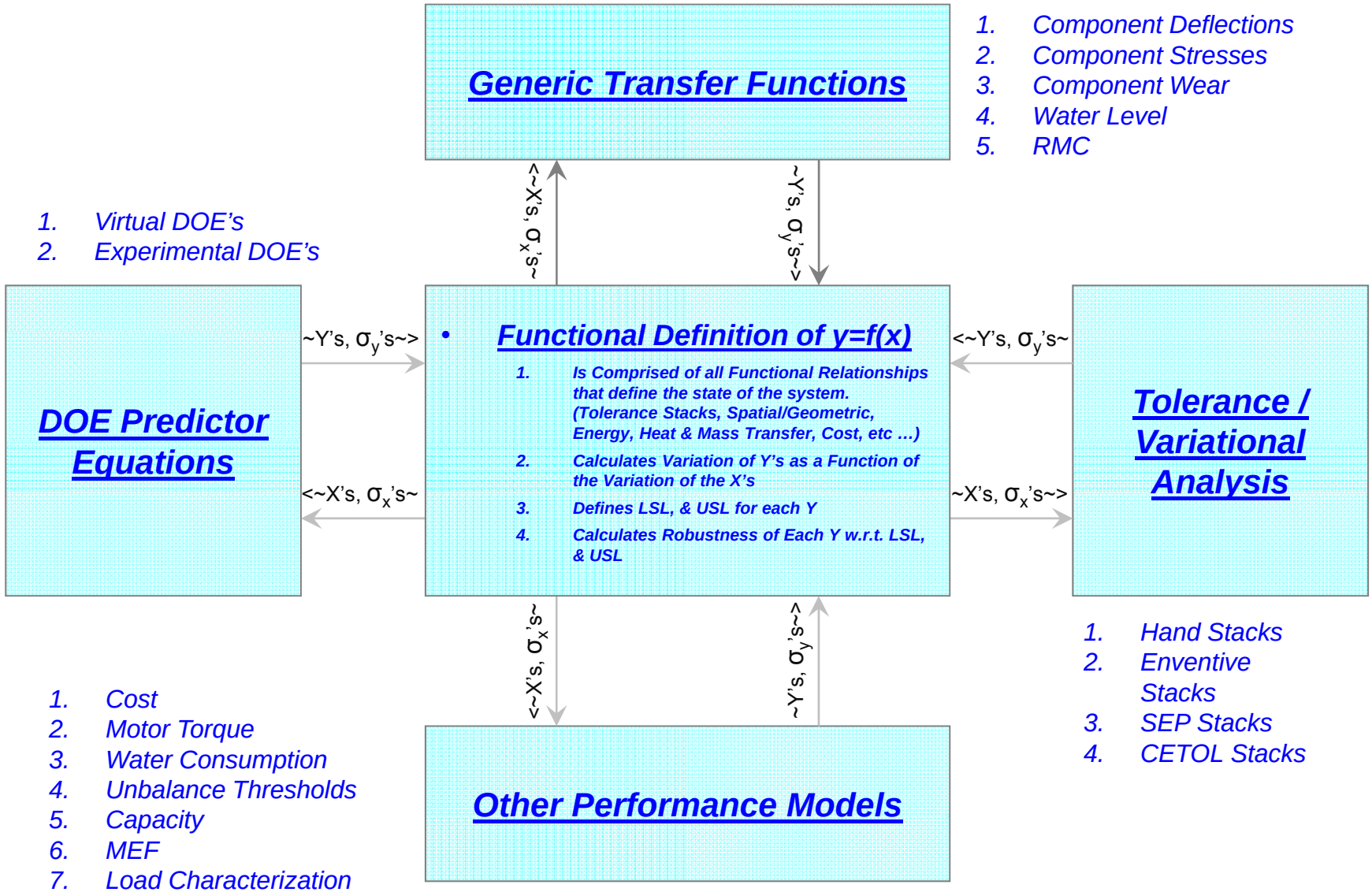






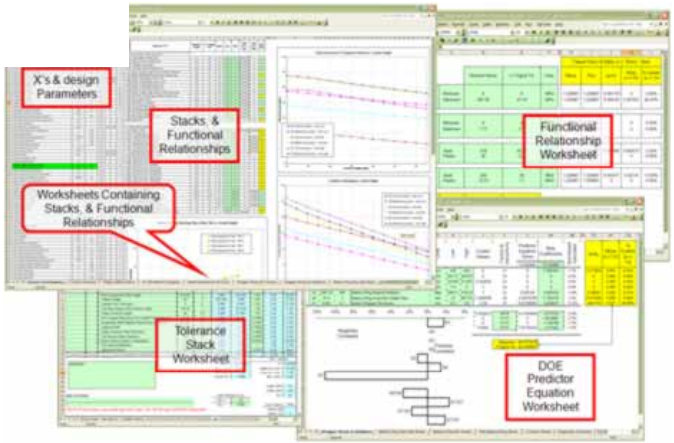


System & Process - Master Top Down Boundary Models



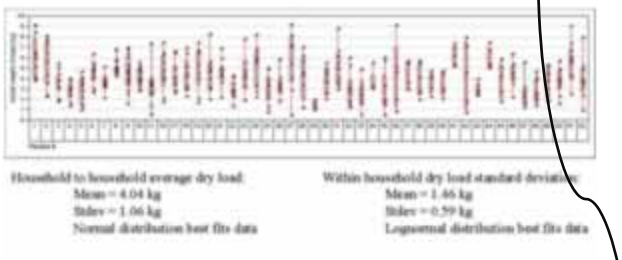
Stochastic Optimizer Master Models (Limited Functional Domains)

- *Three Basic Methods Have Been Used:*
  - *"Traditional Numerical Optimization"* Using Gradient, or Evolutionary Search Algorithms
    - Excel Solver – Requires Continuous, Smooth Inference Space
    - Third Party Excel Solvers from Frontline (Much Better …) – Can Handle Non-Smooth Inference Spaces, and Perform Global Optimization
    - Isight Solvers - Can Handle Non-Smooth Inference Spaces with Evolutionary Solver
  - *Multiobjective Optimization*
    - *"Requirements Based Optimization"* Using Numerical Optimization
      - Uses Minimization of Squares to Minimize the Sum of the Residual of Required and Actual Conformance to Target Cpk for a set of Product Requirements
      - Requires Calculation of Cpk w.r.t Target for Each Requirement, Which Requires Calculation of Variation for Each Requirement
    - *"Utopia Point Optimization"* Using Numerical Optimization
      - Define a System Solution that May, or May Not, be Achievable, and then Sum the Squares of the Normalized Residual of the Distance Between Each Optimization Objective and the Utopia Point.
    - *"Pareto Boundary Trade-off Analysis"* Using Numerical Optimization
      - Involves Repeated Optimization of a System while Incrementing a Constraint. Plots of Various Optimal Values Versus the Incremented Constraint are Curves of Best Possible Values for Each Value of the Constraint. An Example would be to Plot Optimal Cost Versus Max Design Load.
  - *Monte Carlo Simulation*
    - *"Pareto Boundary Trade-off Analysis"* Using Monte Carlo Simulation
      - Involves Repeated Evaluation of a System using Randomly Generated Values for Each Input, and then Plotting an Optimization Objective Versus a Constraint. The Boundary of the Resulting Plot represents the Optimal Pareto Boundary of the Objective w.r.t. the Constraint.
    - *"Optimal Design Space Analysis"* Using Monte Carlo Simulation
      - Involves Repeated Evaluation of a System using Randomly Generated Values for Each Input, and then Repeatedly Sorting the Results to find a Subset that Meets all Requirements. Potential Optimal Solutions for the System Can then Often be Found Through Inspection.



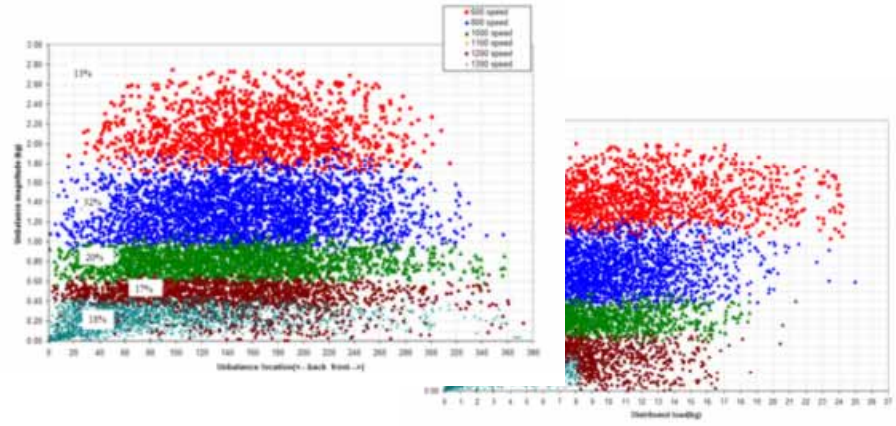
ATTRIBUTE-FUNCTION STOCHASTIC BOUNDARY MODEL

Amount of laundry per load

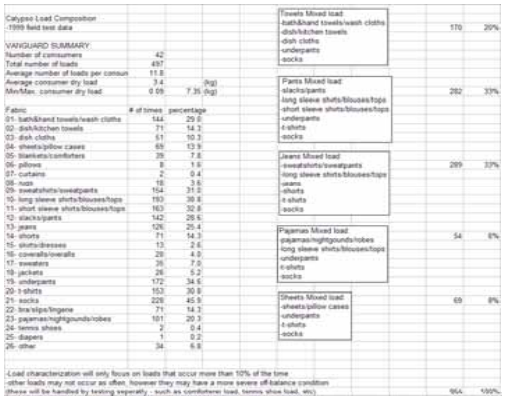


Household to household average dry load:
Mean = 4.04 kg
Stdev = 1.06 kg
Normal distribution best fits data

Within household dry load standard deviation:
Mean = 1.46 kg
Stdev = 0.59 kg
Lognormal distribution best fits data



To get washer loading characteristics



Calypso Load Composition
-1999 field test data

VANGUARD SUMMARY:					
Number of consumers	42				
Total number of loads	497				
Average number of loads per consum	11.8				
Average consumer dry load	3.4	(kg)			
Min/Max. consumer dry load	0.05	7.35 (kg)			
Fabric	# of times	percentage			
01- bath&hand towels/wash cloths	144	29.0			
02- dish/kitchen towels	71	14.3			
03- dish cloths	51	10.3			
04- sheets/pillow cases	69	13.9			
05- blankets/comforters	39	7.8			
06- pillows	8	1.6			
07- curtains	2	0.4			
08- rugs	18	3.6			
09- sweatshirts/sweatpants	154	31.0			
10- long sleeve shirts/blouses/tops	193	38.8			
11- short sleeve shirts/blouses/tops	163	32.8			
12- slacks/pants	142	28.6			
13- jeans	126	25.4			
14- shorts	71	14.3			
15- shirts/dresses	13	2.6			
16- coveralls/overalls	20	4.0			
17- sweaters	35	7.0			
18- jackets	26	5.2			
19- underpants	172	34.6			
20- t-shirts	153	30.8			
21- socks	228	45.9			
22- bra/slips/lingerie	71	14.3			
23- pajamas/nightgounds/robes	101	20.3			
24- tennis shoes	2	0.4			
25- diapers	1	0.2			
26- other	34	6.8			

Towels Mixed load: bath&hand towels/wash cloths, dish/kitchen towels, dish cloths, underpants, socks — 170, 20%

Pants Mixed load: slacks/pants, long sleeve shirts/blouses/tops, short sleeve shirts/blouses/tops, underpants, t-shirts, socks — 282, 33%

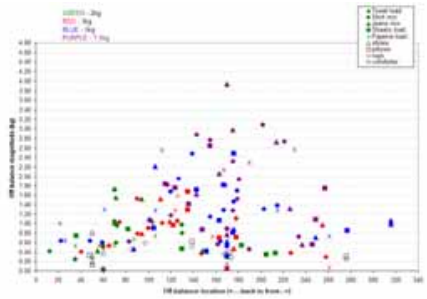
Jeans Mixed load: sweatshirts/sweatpants, long sleeve shirts/blouses/tops, jeans, shorts, t-shirts, socks — 289, 33%

Pajamas Mixed load: pajamas/nightgounds/robes, long sleeve shirts/blouses/tops, underpants, t-shirts, socks — 54, 6%

Sheets Mixed load: sheets/pillow cases, underpants, t-shirts, socks — 69, 8%

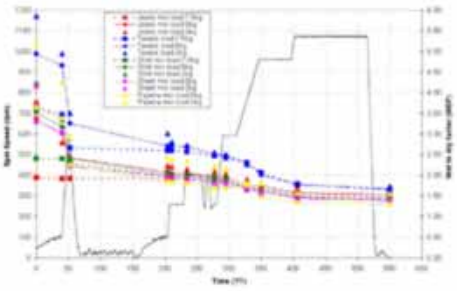
-Load characterization will only focus on loads that occur more than 10% of the time
-other loads may not occur as often, however they may have a more severe off-balance condition
(these will be handled by testing seperatly - such as comforter load, tennis shoe load, etc)

Type of laundry washed

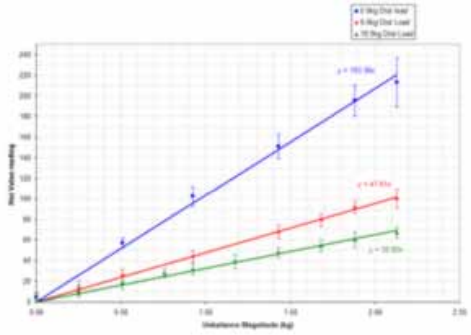


Measured unbalance properties

Coupled with fabric extraction data

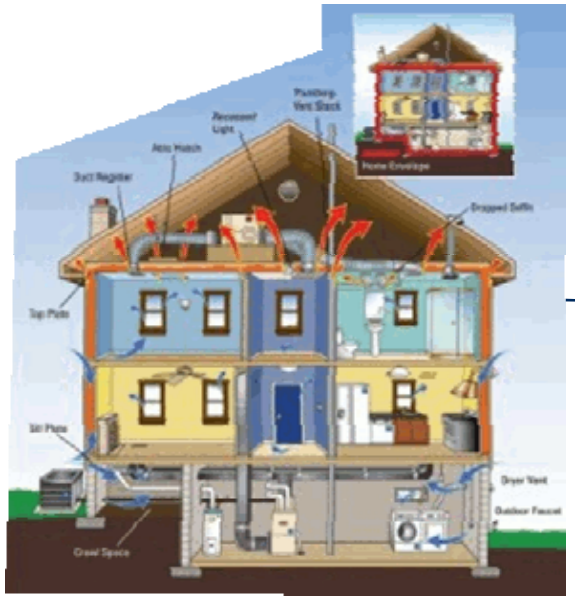


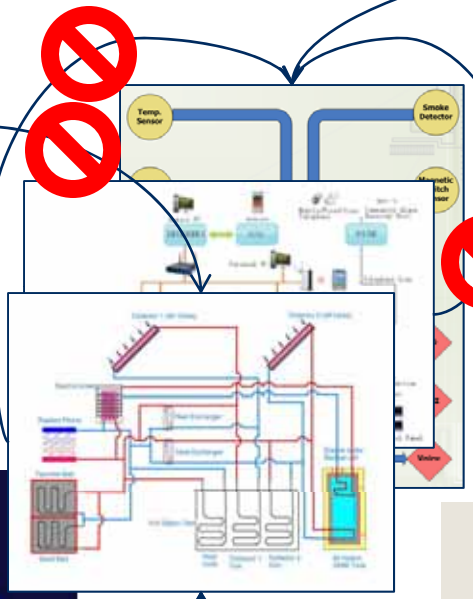
And unbalance management

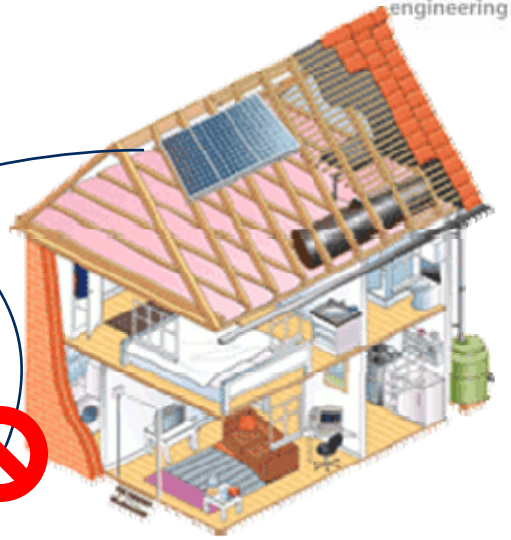


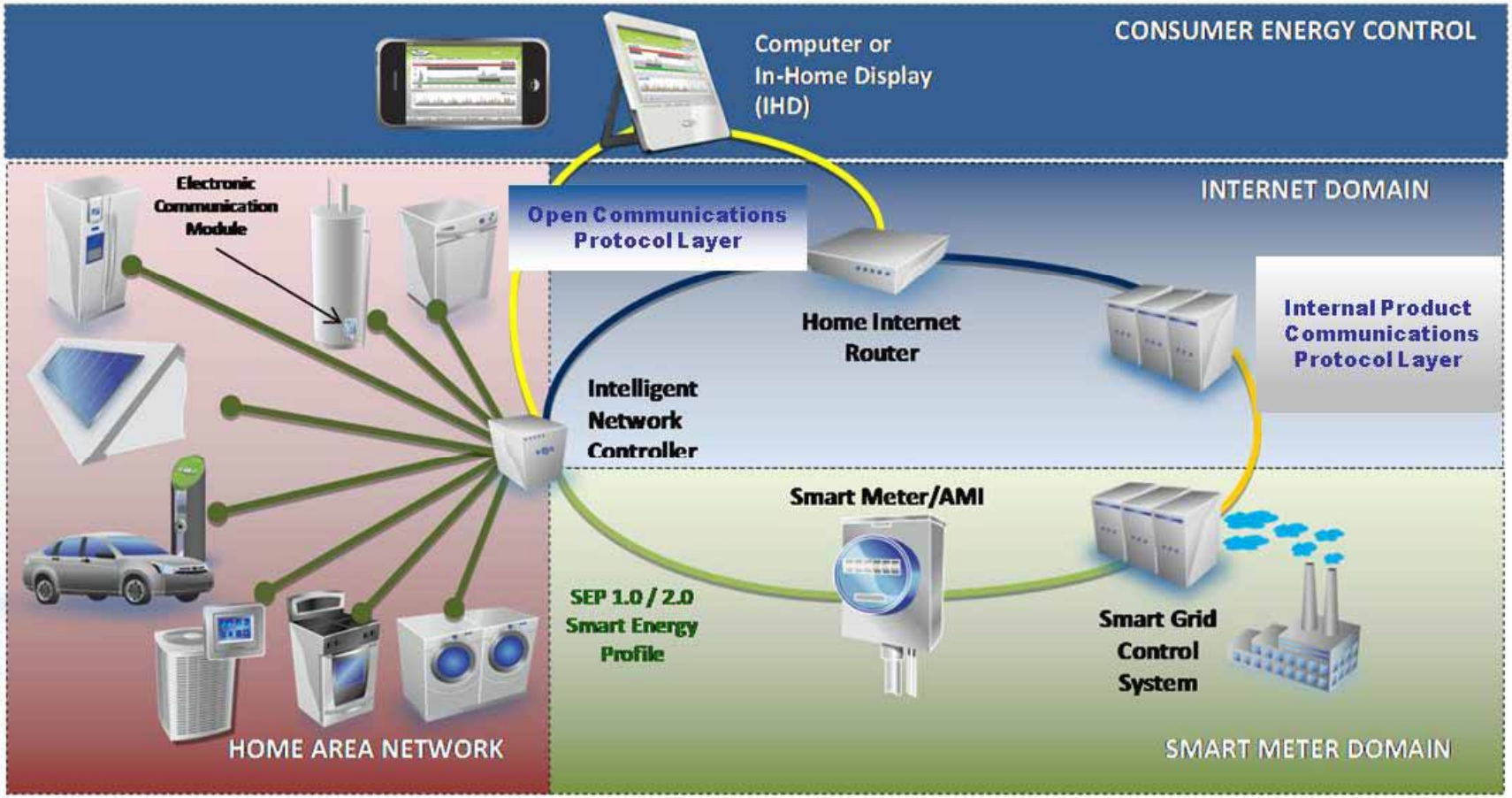
Whirlpool

The Era of Home System Modeling: Models are Not yet well integrated…



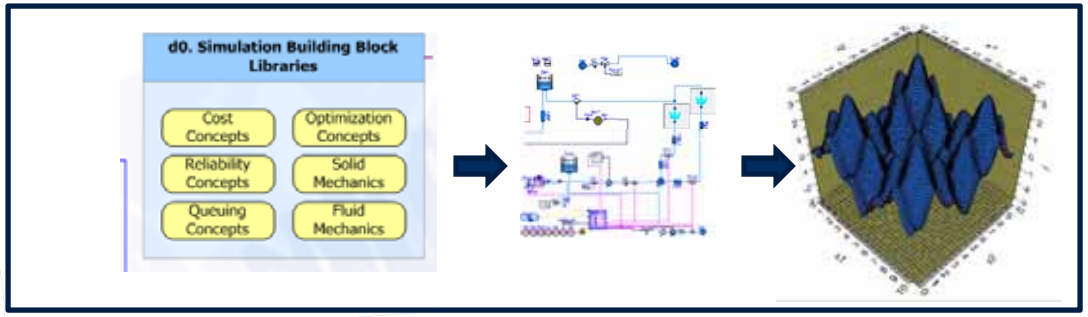





CONSUMER ENERGY CONTROL
Computer or
In-Home Display
(IHD)
Electronic
Communication
Module
Open Communications
Protocol Layer
INTERNET DOMAIN
Home Internet
Router
Internal Product
Communications
Protocol Layer
Intelligent
Network
Controller
Smart Meter/AMI
SEP 1.0 / 2.0
Smart Energy
Profile
Smart Grid
Control
System
HOME AREA NETWORK
SMART METER DOMAIN

NOTIONAL EXAMPLES OF POSSIBLE MBSE "FRONTIERS"

SOLUTIONS LIBRARY MULTIDIMENSIONAL DYNAMIC TRADE-SPACE



Attributes

Characteristics

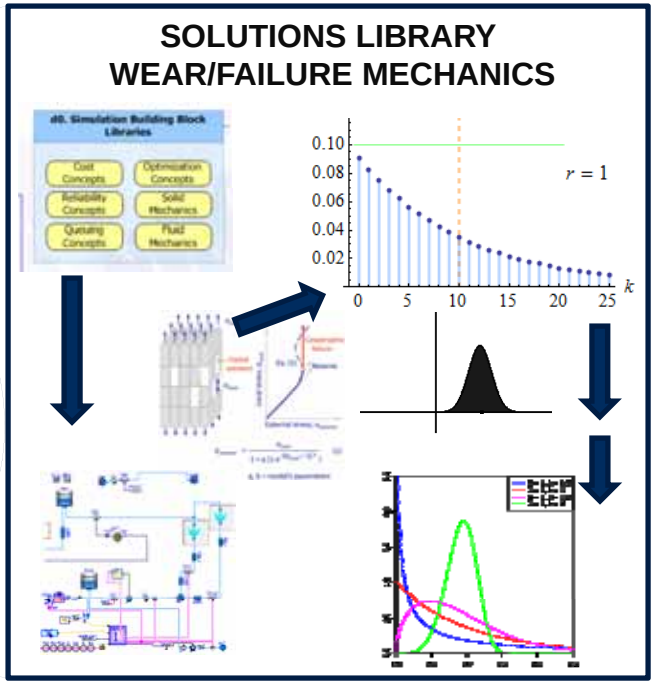
Functions

Sub-Functions

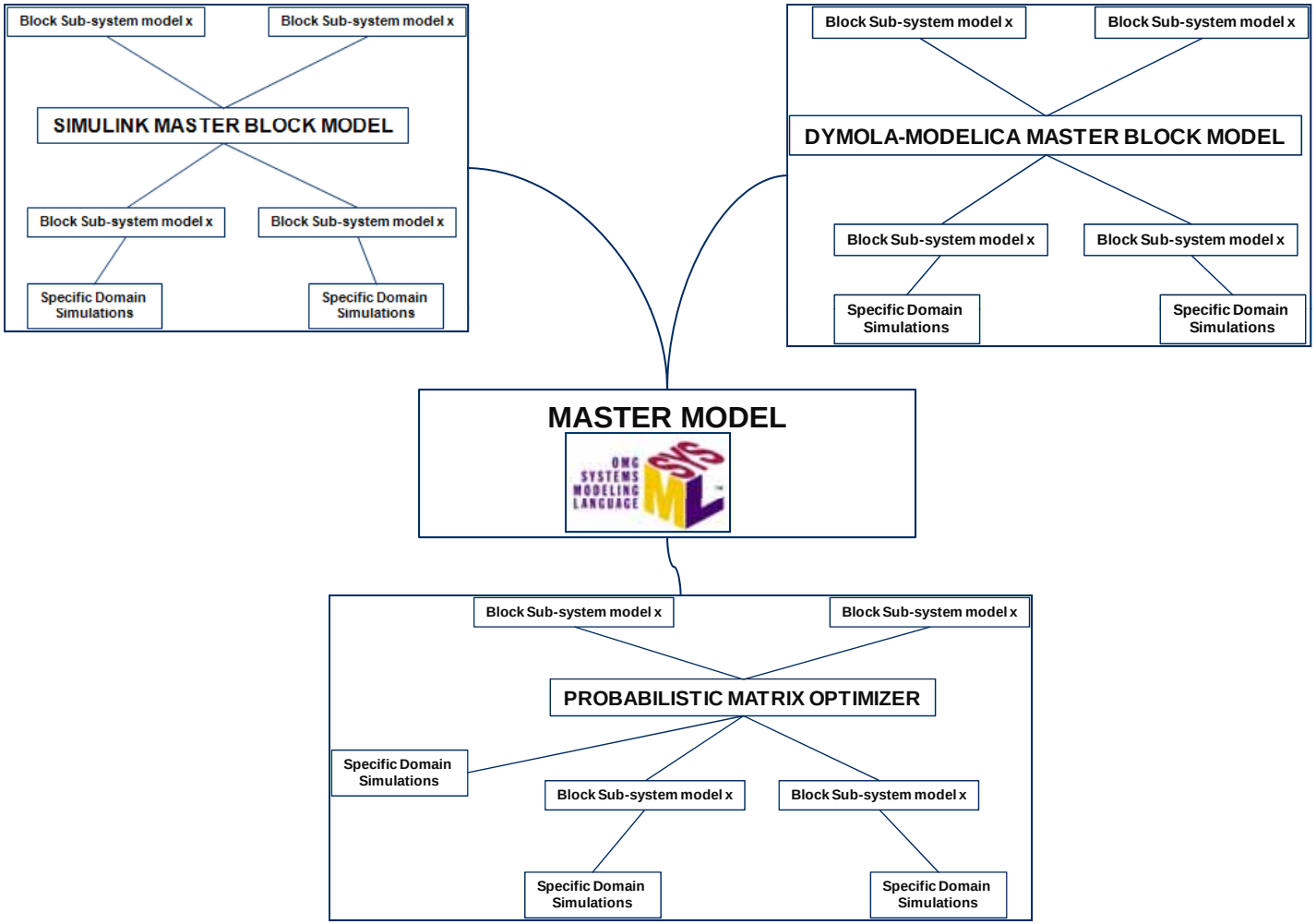
Mechanisms

Phenomenon

SOLUTIONS LIBRARY WEAR/FAILURE MECHANICS



MODEL MAPS AT WHIRLPOOL; A “POSSIBLE” FUTURE



SO WHAT AM I PROPOSING…..

THE PROPOSAL: *"FRONTIERS"* FOR MBSE

- MULTI-DIMENSIONAL /MULTI-DOMAIN MODELING (CONTINUE)
- MODEL BASED ARCHITECTURES (EXTEND)
- OPEN STANDARDS FOR MODELS AND ARCHITECTURES (PERSEVERE)
  - SysML ,Architectural Frameworks, Modelica …etc. "consolidation"
- FUNDAMENTAL RESEARCH AND APPLIED ENGINEERING SCIENCE:
  - System Model Tools and Methods for Applied Research
  - System Model Tools and Methods System Architecture Exploration
  - System Model Tools and Methods for Innovation (Invention)

    (EXPLORE)
- MODELING AS A INTEGRATOR OF KNOWLEDGE
  - Link System Development Initiatives (Lean, etc) to MBSE
  - Link to System Science Initiatives (EXPLORE)

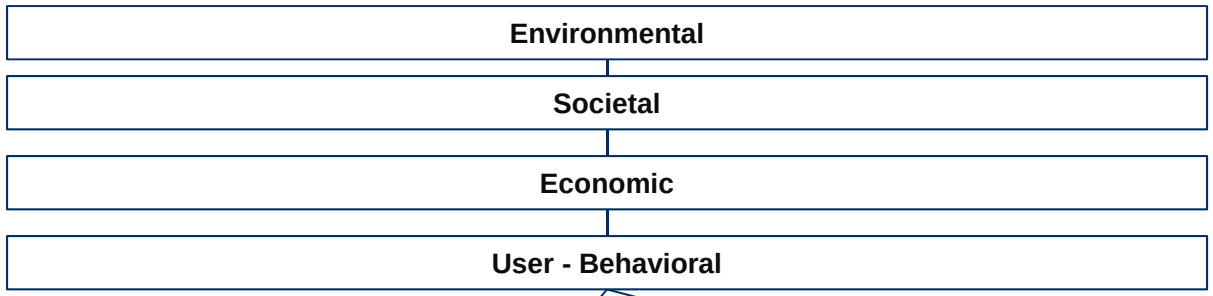
MANY THANKS TO THE AUDIENCE & MBSE FRONTIERS…

…….ANY QUESTIONS ???

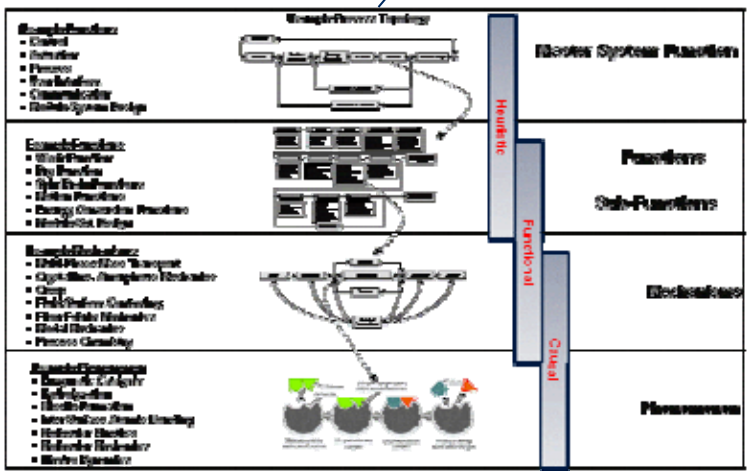
BACKUP SLIDES FOR REFERENCE

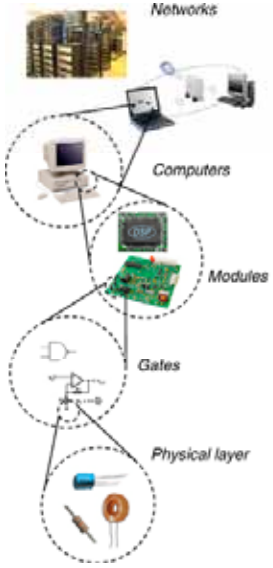
Multi Dimensional Models are Changing Science and Engineering

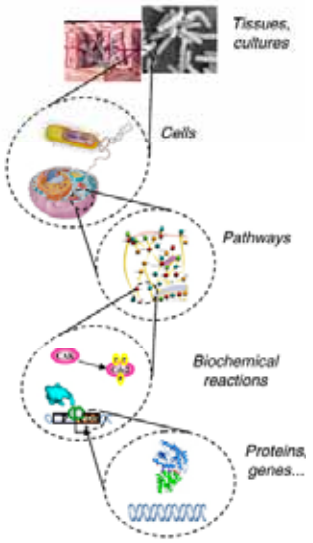
Opportunity for Improvement……



Additional Model Layers……







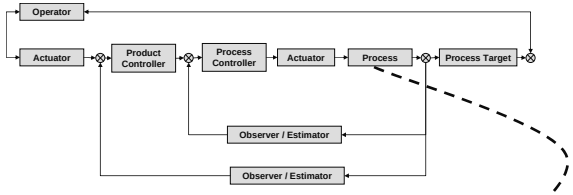
Modeling Depth……

MASTER MODEL LAYERS … DIMENSIONS WE MUST HAVE …

Systems Functional / Process Hierarchy Example

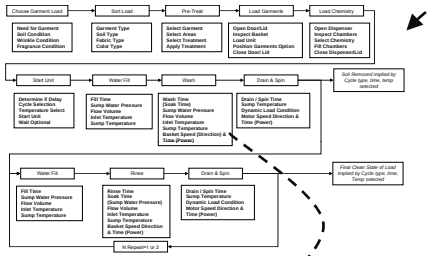
Example Functions
- Control
- Actuation
- Process
- User Interface
- Communication
- Module System Design

Example Process Topology



Master System Function

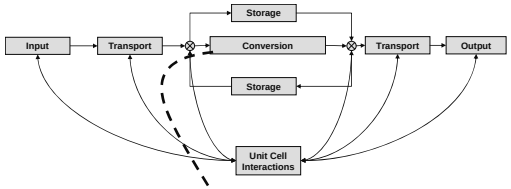
Example Functions
- Wash Function
- Dry Function
- Spin/Drain Functions
- Motion Functions
- Energy Conversion Functions
- Module Set Design



Functions

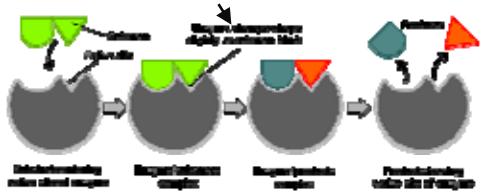
Sub-Functions

Example Mechanisms
- Multi-Phase Mass Transport
- Crystalline- Amorphous Mechanics
- Creep
- Fluid Surface Contacting
- Fiber Fabric Mechanics
- Modal Mechanics
- Process Chemistry



Mechanisms

Example Phenomenon
- Enzymatic Catalysis
- Hydrolyzation
- Micelle Formation
- Inter Surface Atomic Bonding
- Molecular Kinetics
- Molecular Mechanics
- Electro Dynamics



Phenomenon

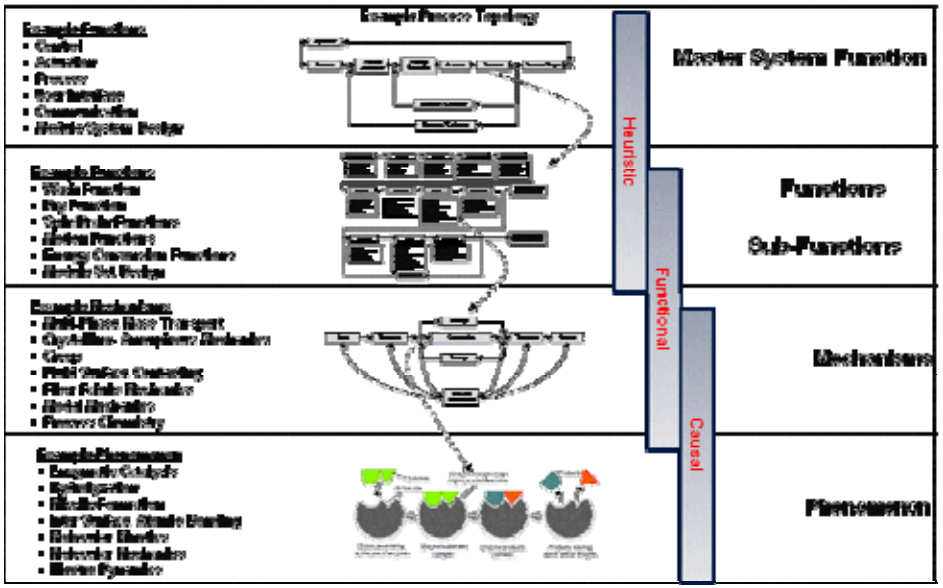
Heuristic

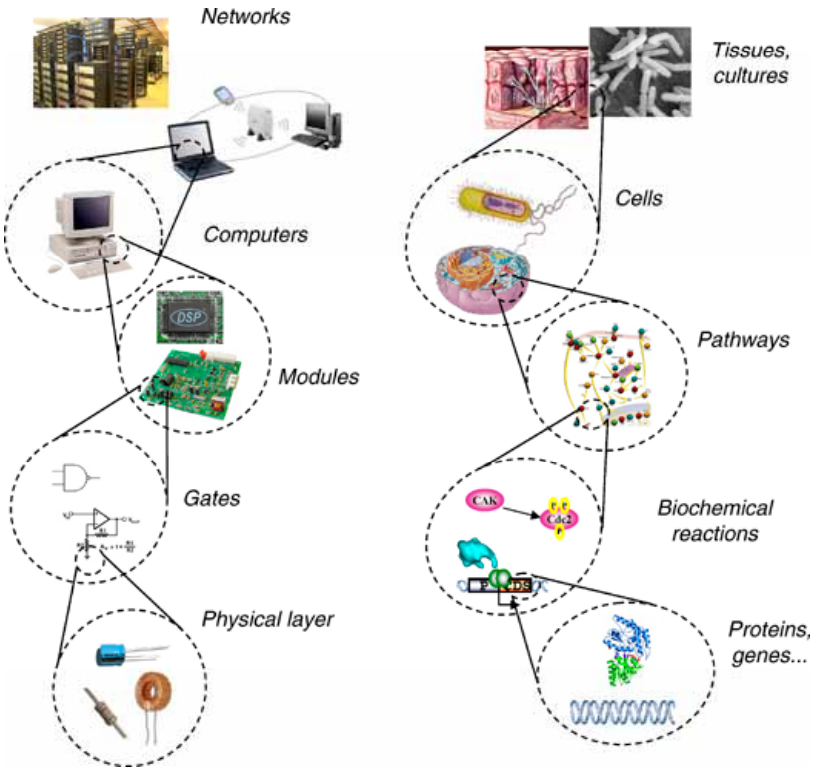
Functional

Causal

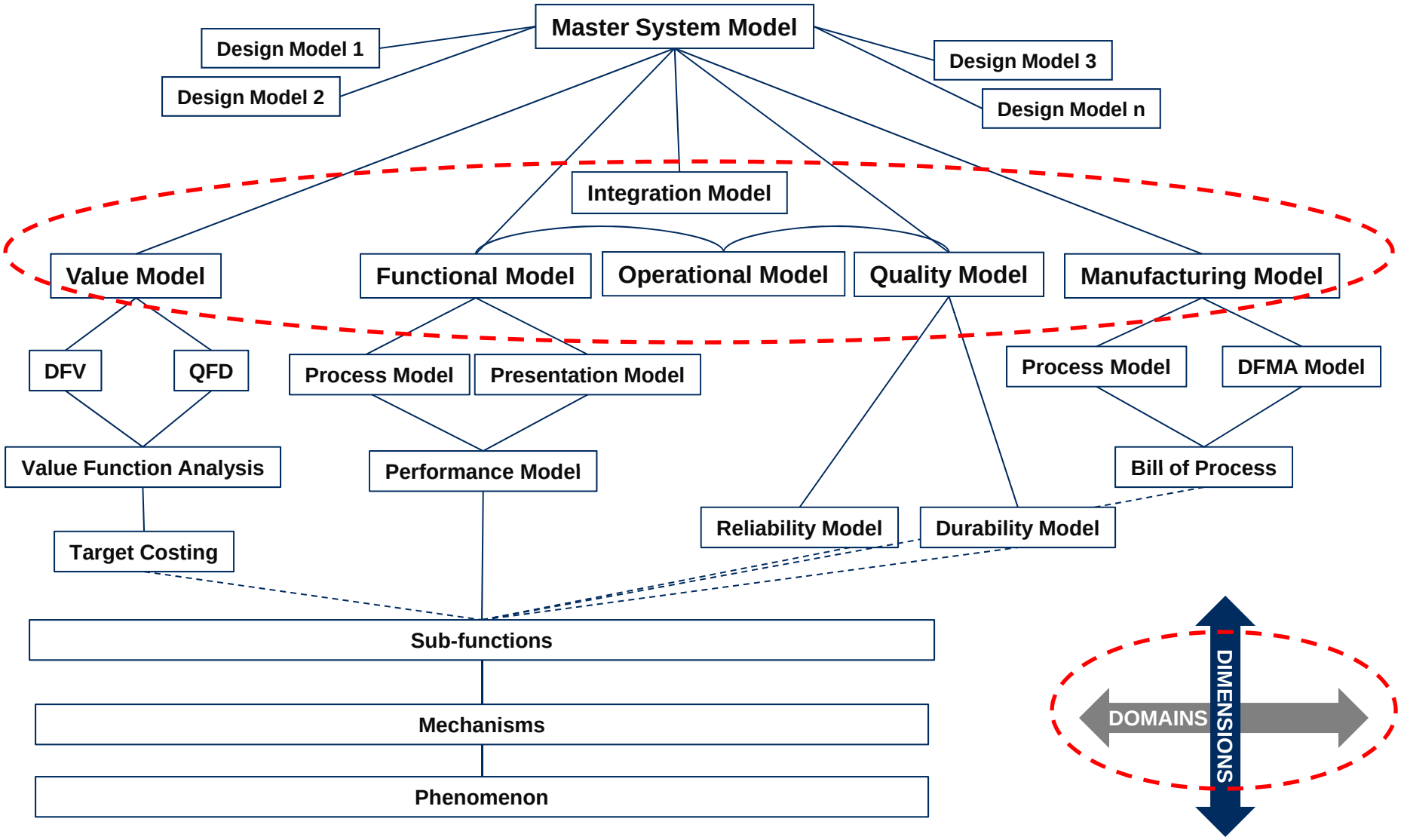
Multi Dimensional Models are Changing all of Science and Engineering (as well)

…..BUT SOME LAYERS ARE UNDERDEVELOPED…





System Models Improvement across Dimensions & Domains



System Model Levels of Predictivity