Model-Based Systems Engineering:

Past, Present and Future

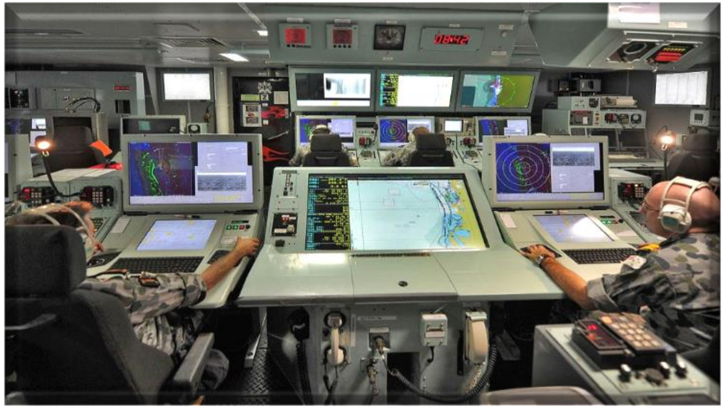
No Magic

The Truth is in the Models™

What is Systems Engineering?

- Interdisciplinary in nature
- Design and management of complex systems
- Focuses on the whole as opposed to the parts
- Identify goals, create alternative solutions, select best design, verify proper implementation and integration, assess how well requirements were met
- The engineering discipline that acts as the voice of the customer

Where is it used?



Systems Engineering is used to some degree on almost all products/systems of any significance today, whether as a formal practice or not.

Why is it important today?

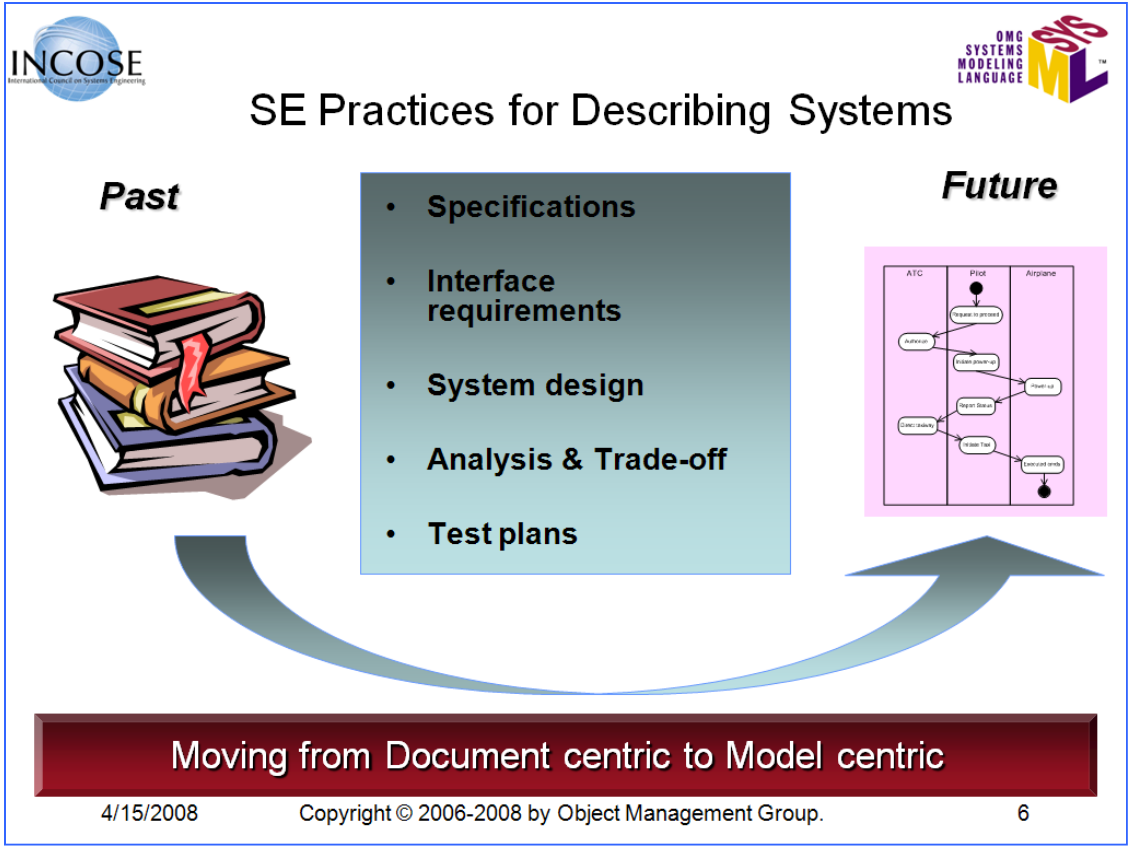
- Systems are becoming increasingly complex
- Increase in subsystems, components, data, variables

This has been an underserved discipline!

State of Practice in Systems Engineering: Documents and Spreadsheets Rule!

- Document based approach works, but…
- How do we keep documents and designs properly synched?
- According to research, the majority of serious defects occur in early phases of the system lifecycle

INCOSE and OMG: MBSE is the Future SE



SE Practices for Describing Systems

Past

Future

- **Specifications**
- **Interface requirements**
- **System design**
- **Analysis & Trade-off**
- **Test plans**

Moving from Document centric to Model centric

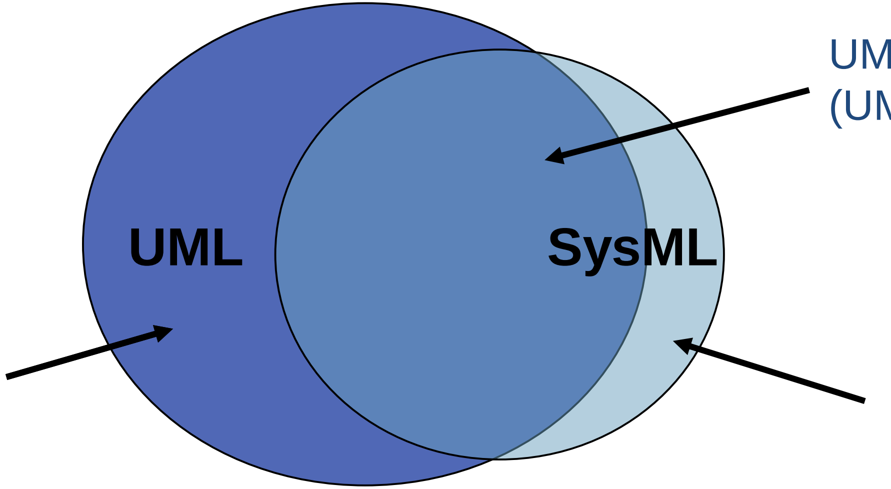
4/15/2008 Copyright © 2006-2008 by Object Management Group. 6

What is Model Based Systems Engineering?

MBSE is a disciplined, rigorous approach to systems engineering that uses visual modeling to support requirements, design, and analysis through conceptual, logical, and later phases of the system life cycle

Systems Modeling Language (SysML)

- OMG Systems Modeling Language (SysML) is a graphical modeling language for specification, analysis, design, verification and validation of systems
- Dedicated for modeling complex systems that may include hardware, software, information, personnel, procedures, facilities, etc.



UML reused by SysML (UML4SysML)

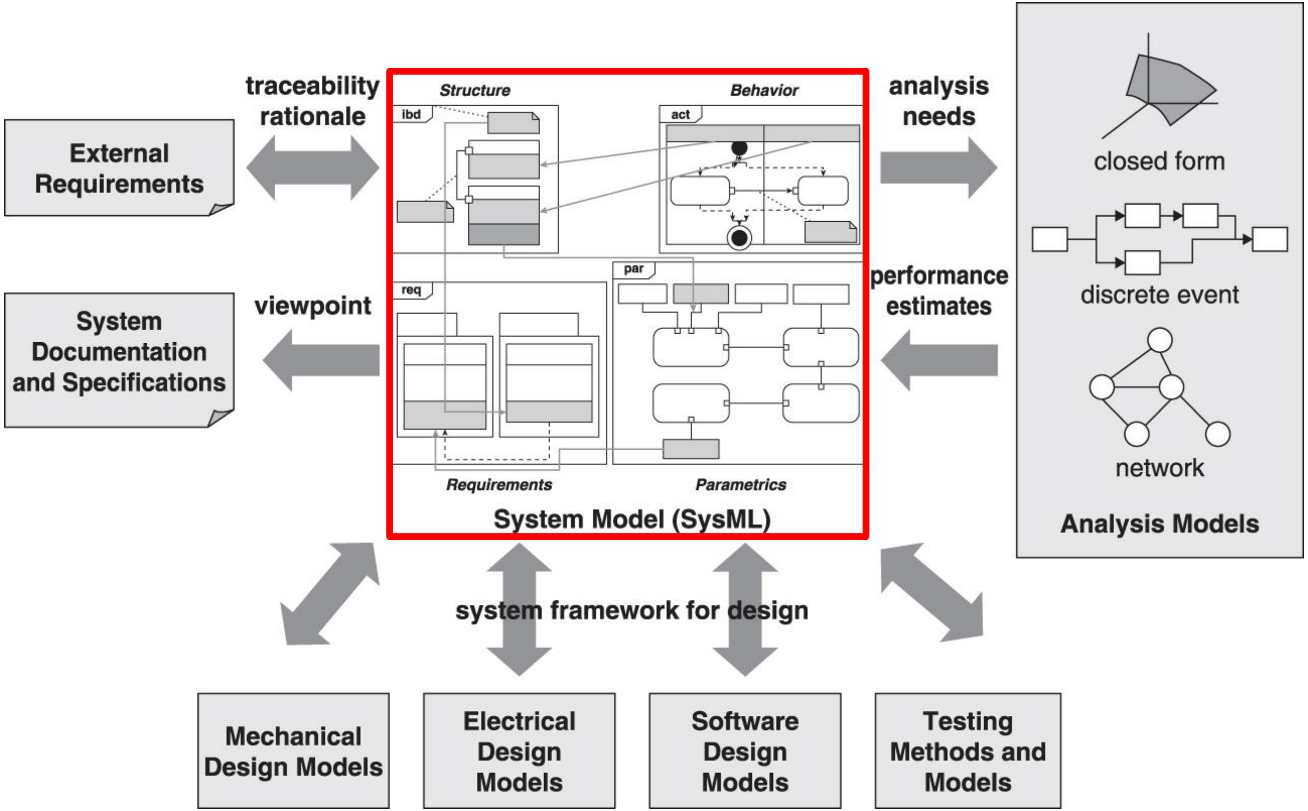
Not required by SysML

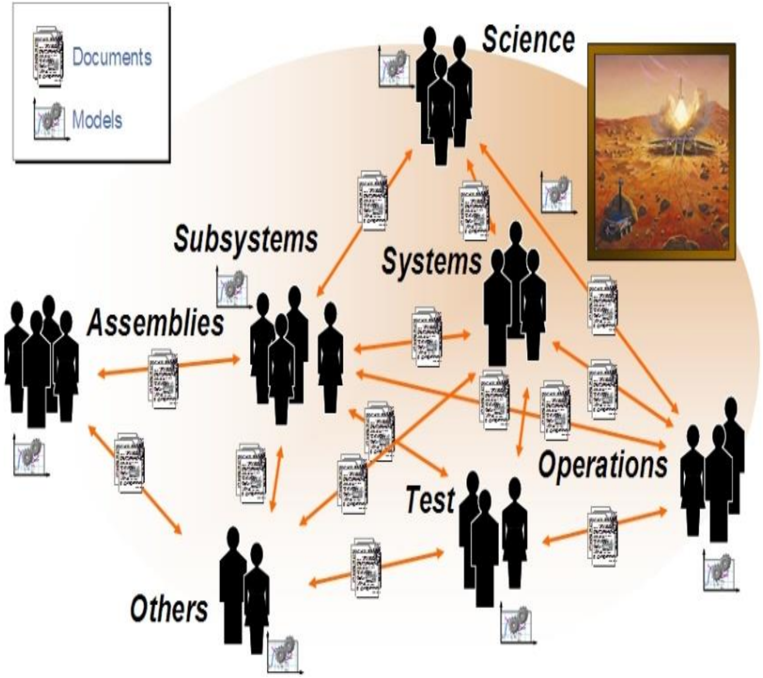
SysML’s extensions to UML

Why are visual models important?

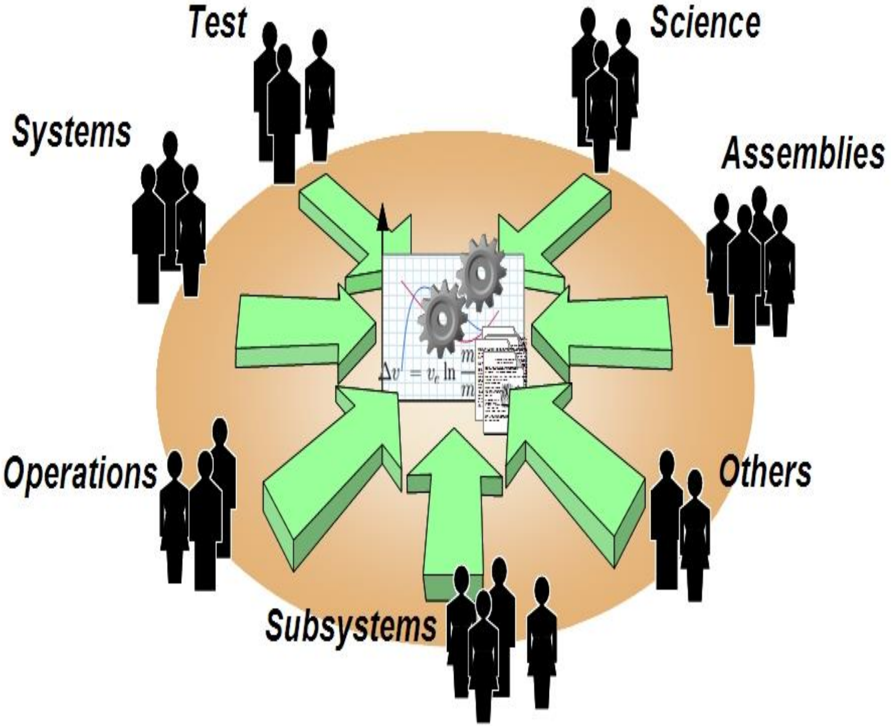
- Simplify the representation of systems
- Eliminate or reduce ambiguity concerning concepts, relationships, intent, or structure
- Improves communication and understanding
- Provide a technical baseline
- Used for validation and verification at multiple stages in the development cycle, allowing for earlier detection of problems and defects.

System Model as an Integration Framework





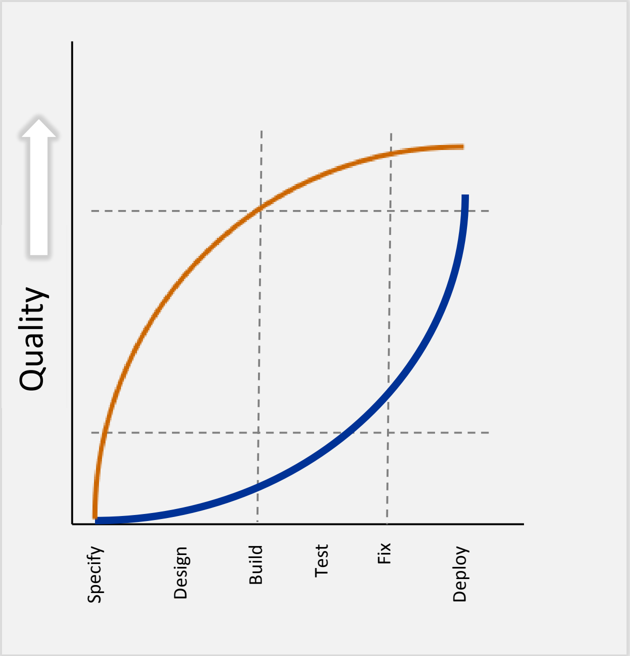
Today: Standalone models related through documents



Future: Shared system model with multiple views, and connected to discipline models

Paradigm Shift

Old design methodologies rely on build, test, fix



- Defects detected earlier in the process
- Less expensive to fix at these earlier stages
- Overall product quality improves

No longer a revolution

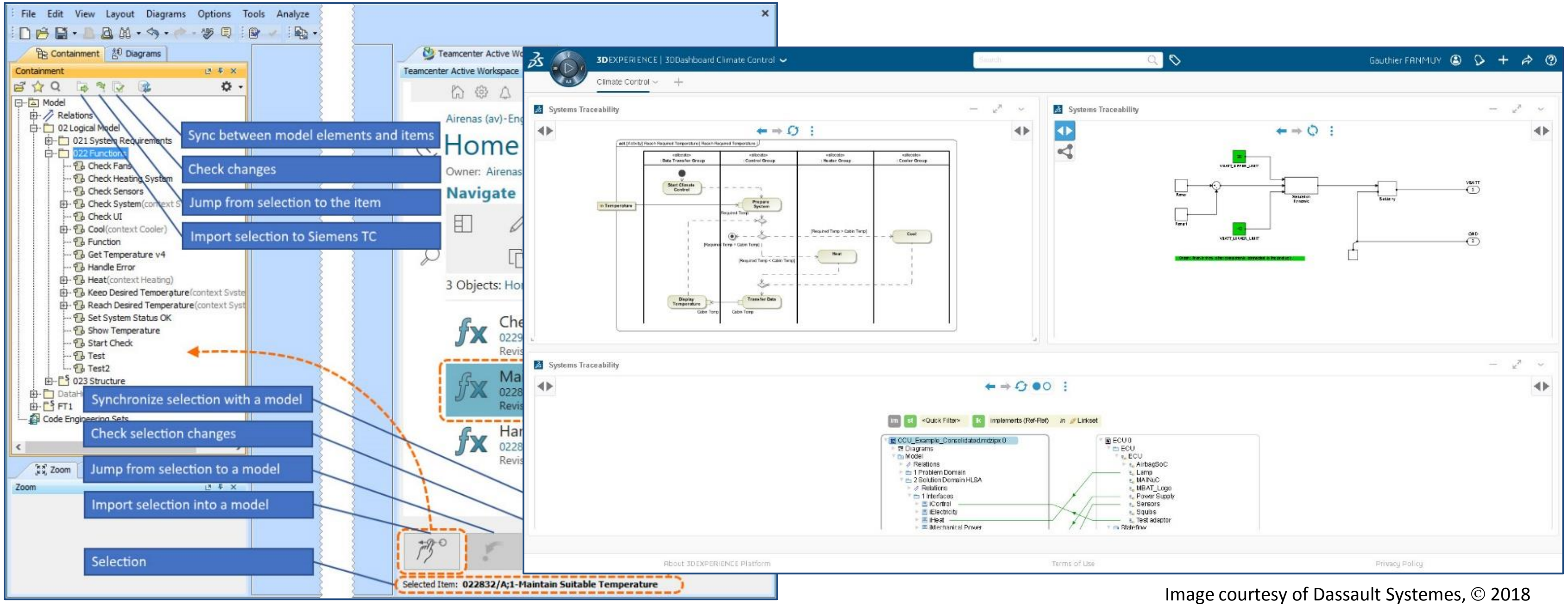
- It’s an EVOLUTION
  - SysML is changing to enhance usability, facilitate exchange of model data, and increase adoption
  - Integrating with PLM
  - Increased demand for interoperability with detailed design tools
  - Full system simulation
  - AI?

SysML v2 Objectives

- Improved precision and effectiveness
- Better consistency among language concepts
- Interoperability with other engineering tools
- Enhanced usability for both developers and consumers

PLM Integration

Integrating to PLM allows for automated data interchange between SE and other disciplines



Sync between model elements and items

Check changes

Jump from selection to the item

Import selection to Siemens TC

Synchronize selection with a model

Check selection changes

Jump from selection to a model

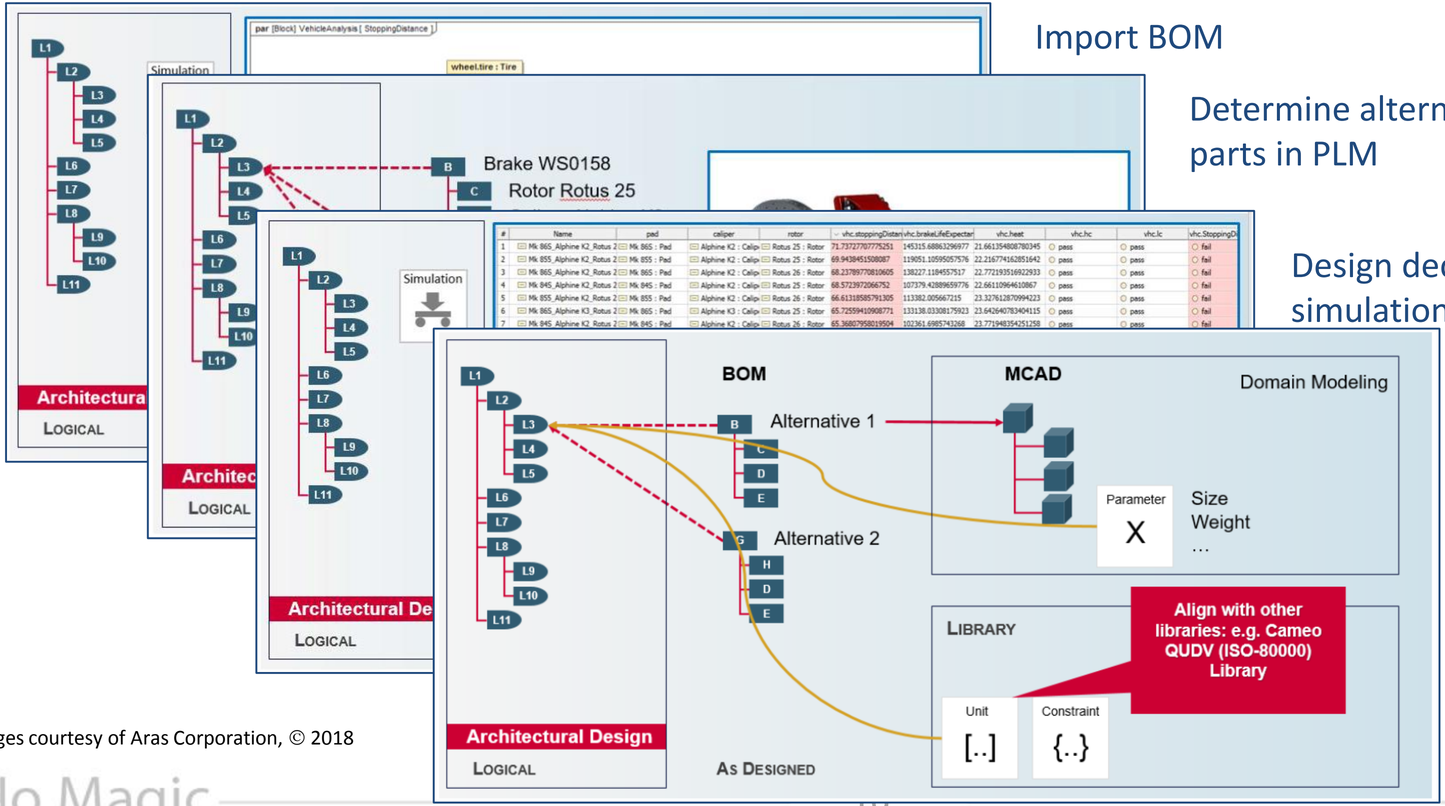
Import selection into a model

Selection

Selected Item: 022832/A;1-Maintain Suitable Temperature

Image courtesy of Dassault Systemes, © 2018

Deeper Use Case



#	Name	pad	caliper	rotor	vhc.stoppingDistan	vhc.brakeLifeExpectar	vhc.heat	vhc.hc	vhc.lc	vhc.StoppingDi
1	Mk 86S_Alphine K2_Rotus 2	Mk 86S : Pad	Alphine K2 : Calip	Rotus 25 : Rotor	71.73727707775251	145315.68863296977	21.661354808780345	○ pass	○ pass	○ fail
2	Mk 85S_Alphine K2_Rotus 2	Mk 85S : Pad	Alphine K2 : Calip	Rotus 25 : Rotor	69.9438451508087	119051.10595057576	22.216774162851642	○ pass	○ pass	○ fail
3	Mk 86S_Alphine K2_Rotus 2	Mk 86S : Pad	Alphine K2 : Calip	Rotus 26 : Rotor	68.23789770810605	138227.1184557517	22.772193516922933	○ pass	○ pass	○ fail
4	Mk 84S_Alphine K2_Rotus 2	Mk 84S : Pad	Alphine K2 : Calip	Rotus 25 : Rotor	68.5723972066752	107379.42889659776	22.66110964610867	○ pass	○ pass	○ fail
5	Mk 85S_Alphine K2_Rotus 2	Mk 85S : Pad	Alphine K2 : Calip	Rotus 26 : Rotor	66.61318585791305	113382.005667215	23.327612870994223	○ pass	○ pass	○ fail
6	Mk 86S_Alphine K3_Rotus 2	Mk 86S : Pad	Alphine K3 : Calip	Rotus 25 : Rotor	65.72559410908771	133138.03308175923	23.642640783404115	○ pass	○ pass	○ fail
7	Mk 84S_Alphine K2_Rotus 2	Mk 84S : Pad	Alphine K2 : Calip	Rotus 26 : Rotor	65.36807958019504	102361.6985743268	23.771948354251258	○ pass	○ pass	○ fail

Align with other libraries: e.g. Cameo QUDV (ISO-80000) Library

Import BOM

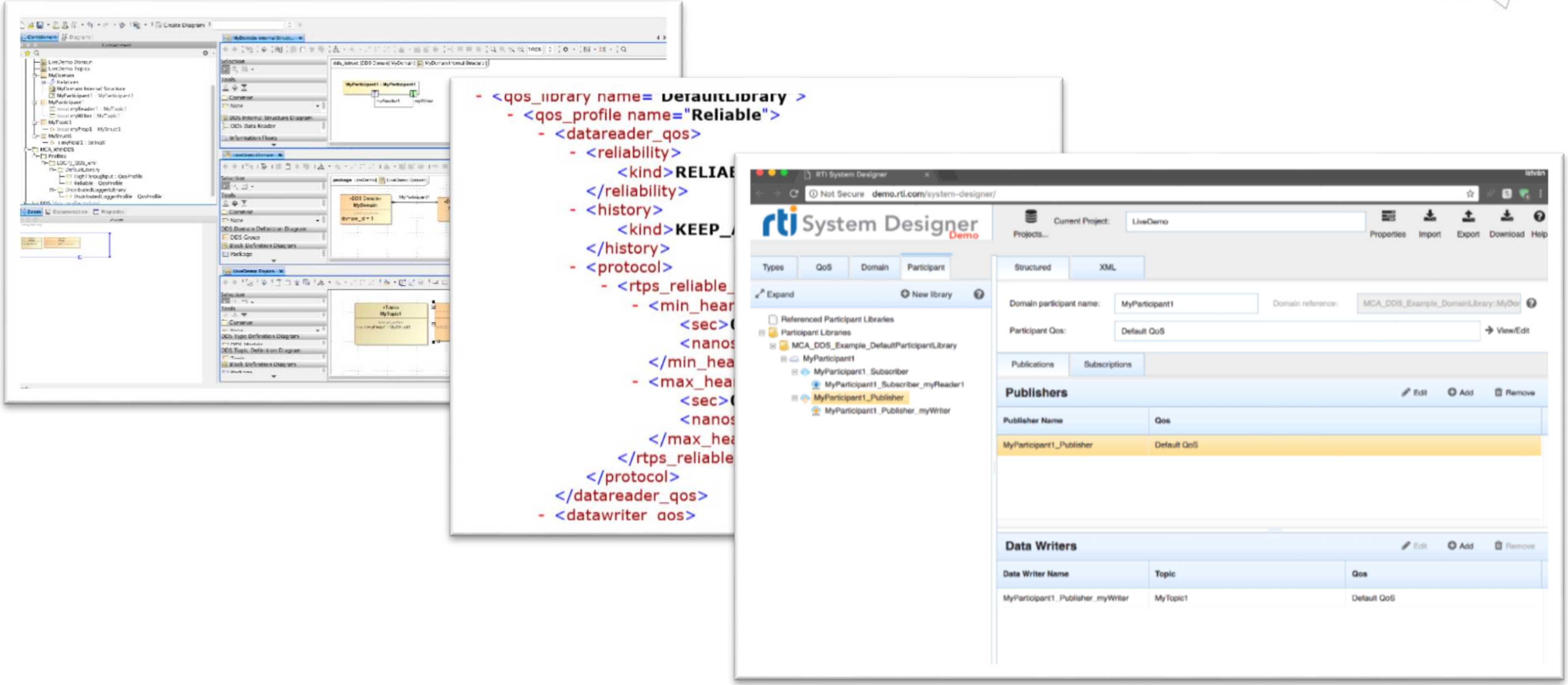
Determine alternatives based on parts in PLM

Design decision based on simulation of all combinations

Publish back to PLM for domain specific design review

Images courtesy of Aras Corporation, © 2018

Detailed Design Exchange - DDS



```
- <qos_library name="DefaultLibrary">
  - <qos_profile name="Reliable">
    - <datareader_qos>
      - <reliability>
          <kind>RELIAE
        </reliability>
      - <history>
          <kind>KEEP_
        </history>
      - <protocol>
        - <rtps_reliable_
          - <min_hear
              <sec>
              <nanos
            </min_hea
          - <max_hea
              <sec>
              <nanos
            </max_hea
          </rtps_reliable
        </protocol>
      </datareader_qos>
    - <datawriter_qos>
```

Current Project: LiveDemo

Domain participant name: MyParticipant1

Domain reference: MCA_DDS_Example_DomainLibrary::MyDo

Participant Qos: Default QoS

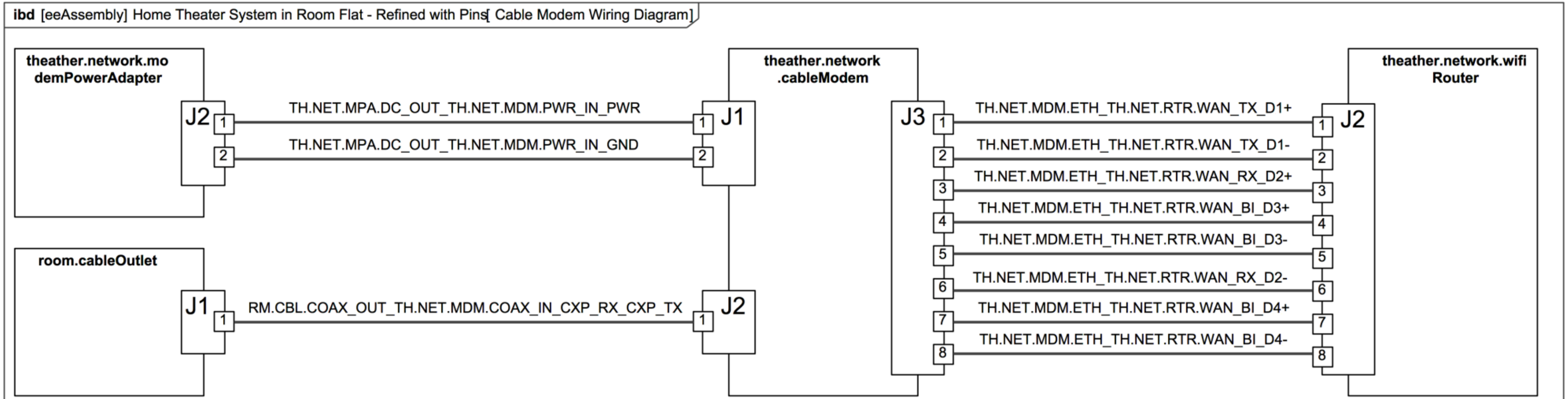
Publishers

Publisher Name	Qos
MyParticipant1_Publisher	Default QoS

Data Writers

Data Writer Name	Topic	Qos
MyParticipant1_Publisher_myWriter	MyTopic1	Default QoS

Wiring Design Model (SysML) - Generated, Fragment



ibd [eeAssembly] Home Theater System in Room Flat - Refined with Pins[Cable Modem Wiring Diagram]

theather.network.modemPowerAdapter

J2

1

2

TH.NET.MPA.DC_OUT_TH.NET.MDM.PWR_IN_PWR

TH.NET.MPA.DC_OUT_TH.NET.MDM.PWR_IN_GND

room.cableOutlet

J1

1

RM.CBL.COAX_OUT_TH.NET.MDM.COAX_IN_CXP_RX_CXP_TX

theather.network.cableModem

J1

1

2

J2

1

J3

1 2 3 4 5 6 7 8

TH.NET.MDM.ETH_TH.NET.RTR.WAN_TX_D1+

TH.NET.MDM.ETH_TH.NET.RTR.WAN_TX_D1-

TH.NET.MDM.ETH_TH.NET.RTR.WAN_RX_D2+

TH.NET.MDM.ETH_TH.NET.RTR.WAN_BI_D3+

TH.NET.MDM.ETH_TH.NET.RTR.WAN_BI_D3-

TH.NET.MDM.ETH_TH.NET.RTR.WAN_RX_D2-

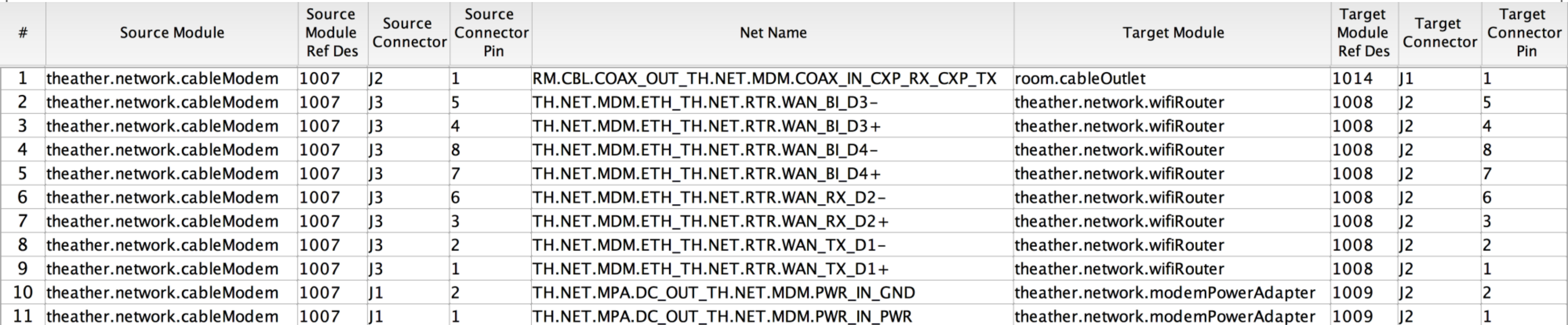
TH.NET.MDM.ETH_TH.NET.RTR.WAN_BI_D4+

TH.NET.MDM.ETH_TH.NET.RTR.WAN_BI_D4-

theather.network.wifiRouter

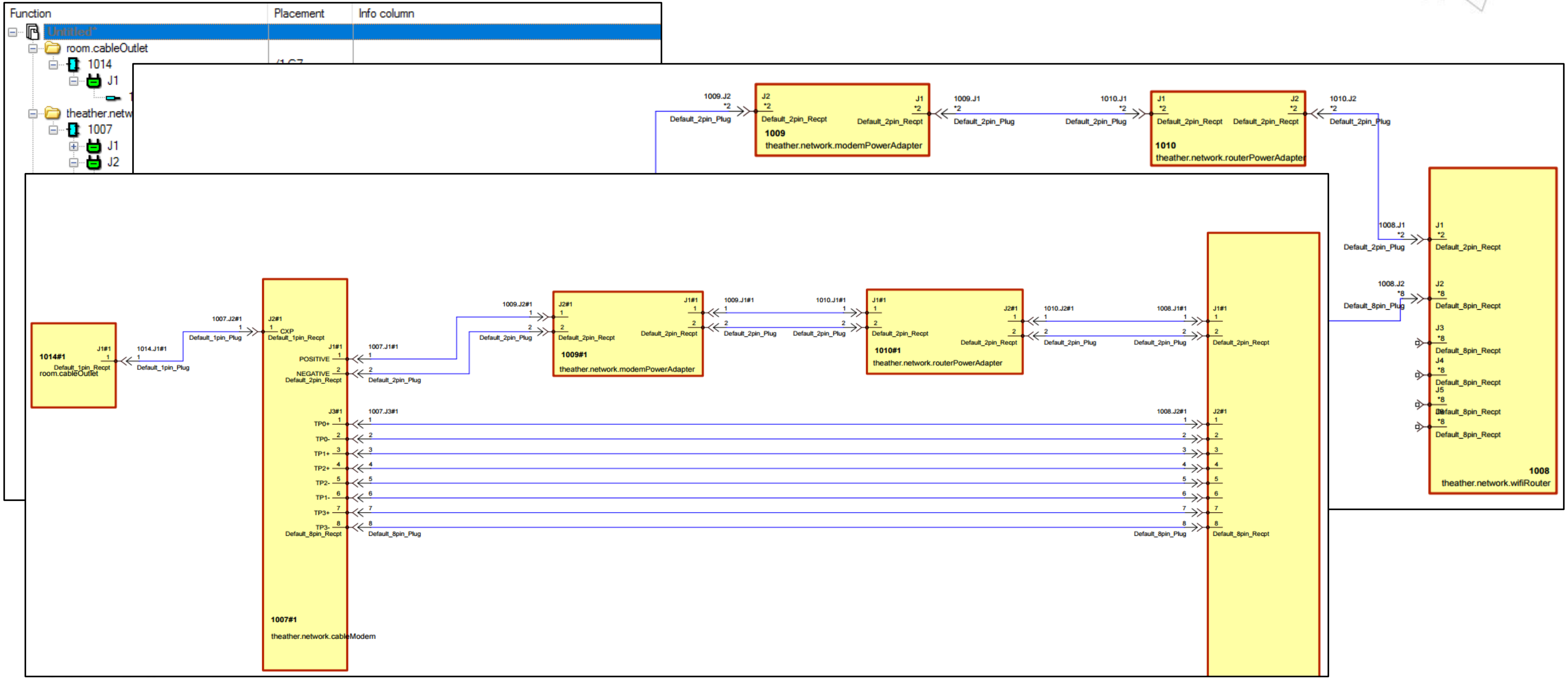
J2

1 2 3 4 5 6 7 8



#	Source Module	Source Module Ref Des	Source Connector	Source Connector Pin	Net Name	Target Module	Target Module Ref Des	Target Connector	Target Connector Pin
1	theather.network.cableModem	1007	J2	1	RM.CBL.COAX_OUT_TH.NET.MDM.COAX_IN_CXP_RX_CXP_TX	room.cableOutlet	1014	J1	1
2	theather.network.cableModem	1007	J3	5	TH.NET.MDM.ETH_TH.NET.RTR.WAN_BI_D3-	theather.network.wifiRouter	1008	J2	5
3	theather.network.cableModem	1007	J3	4	TH.NET.MDM.ETH_TH.NET.RTR.WAN_BI_D3+	theather.network.wifiRouter	1008	J2	4
4	theather.network.cableModem	1007	J3	8	TH.NET.MDM.ETH_TH.NET.RTR.WAN_BI_D4-	theather.network.wifiRouter	1008	J2	8
5	theather.network.cableModem	1007	J3	7	TH.NET.MDM.ETH_TH.NET.RTR.WAN_BI_D4+	theather.network.wifiRouter	1008	J2	7
6	theather.network.cableModem	1007	J3	6	TH.NET.MDM.ETH_TH.NET.RTR.WAN_RX_D2-	theather.network.wifiRouter	1008	J2	6
7	theather.network.cableModem	1007	J3	3	TH.NET.MDM.ETH_TH.NET.RTR.WAN_RX_D2+	theather.network.wifiRouter	1008	J2	3
8	theather.network.cableModem	1007	J3	2	TH.NET.MDM.ETH_TH.NET.RTR.WAN_TX_D1-	theather.network.wifiRouter	1008	J2	2
9	theather.network.cableModem	1007	J3	1	TH.NET.MDM.ETH_TH.NET.RTR.WAN_TX_D1+	theather.network.wifiRouter	1008	J2	1
10	theather.network.cableModem	1007	J1	2	TH.NET.MPA.DC_OUT_TH.NET.MDM.PWR_IN_GND	theather.network.modemPowerAdapter	1009	J2	2
11	theather.network.cableModem	1007	J1	1	TH.NET.MPA.DC_OUT_TH.NET.MDM.PWR_IN_PWR	theather.network.modemPowerAdapter	1009	J2	1

Wiring Schematics (E3.series) - Imported, Fragment



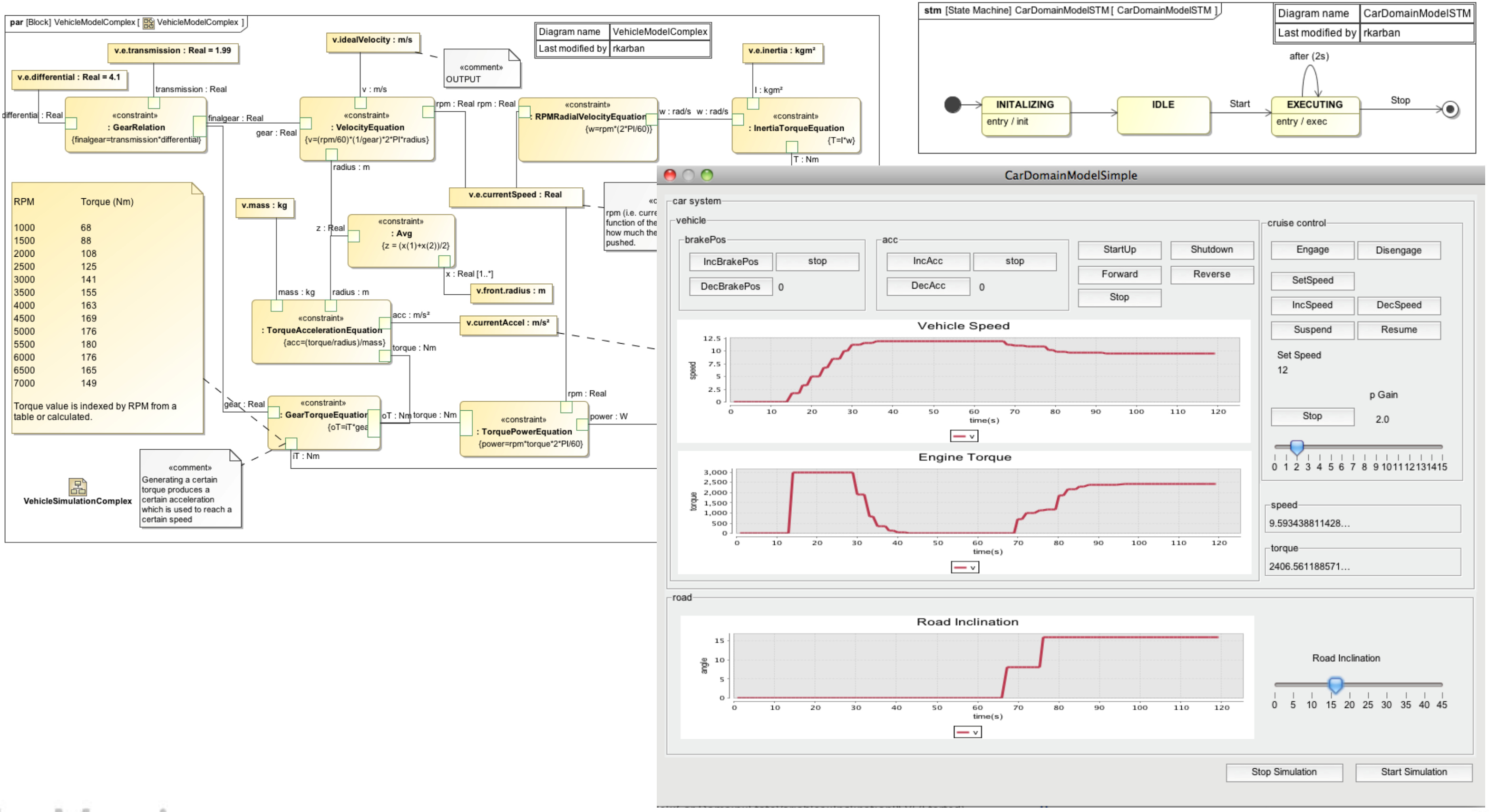
Function | Placement | Info column

- Untitled*
  - room.cableOutlet
    - 1014 /1.C7
      - J1
  - theather.netw
    - 1007
      - J1
      - J2

What is our goal as Systems Engineers?

Ultimately it is about realizing successful systems!

Simulation - Cruise Control Example



RPM	Torque (Nm)
1000	68
1500	88
2000	108
2500	125
3000	141
3500	155
4000	163
4500	169
5000	176
5500	180
6000	176
6500	165
7000	149

Torque value is indexed by RPM from a table or calculated.

«comment»
Generating a certain torque produces a certain acceleration which is used to reach a certain speed

brakePos: 0

acc: 0

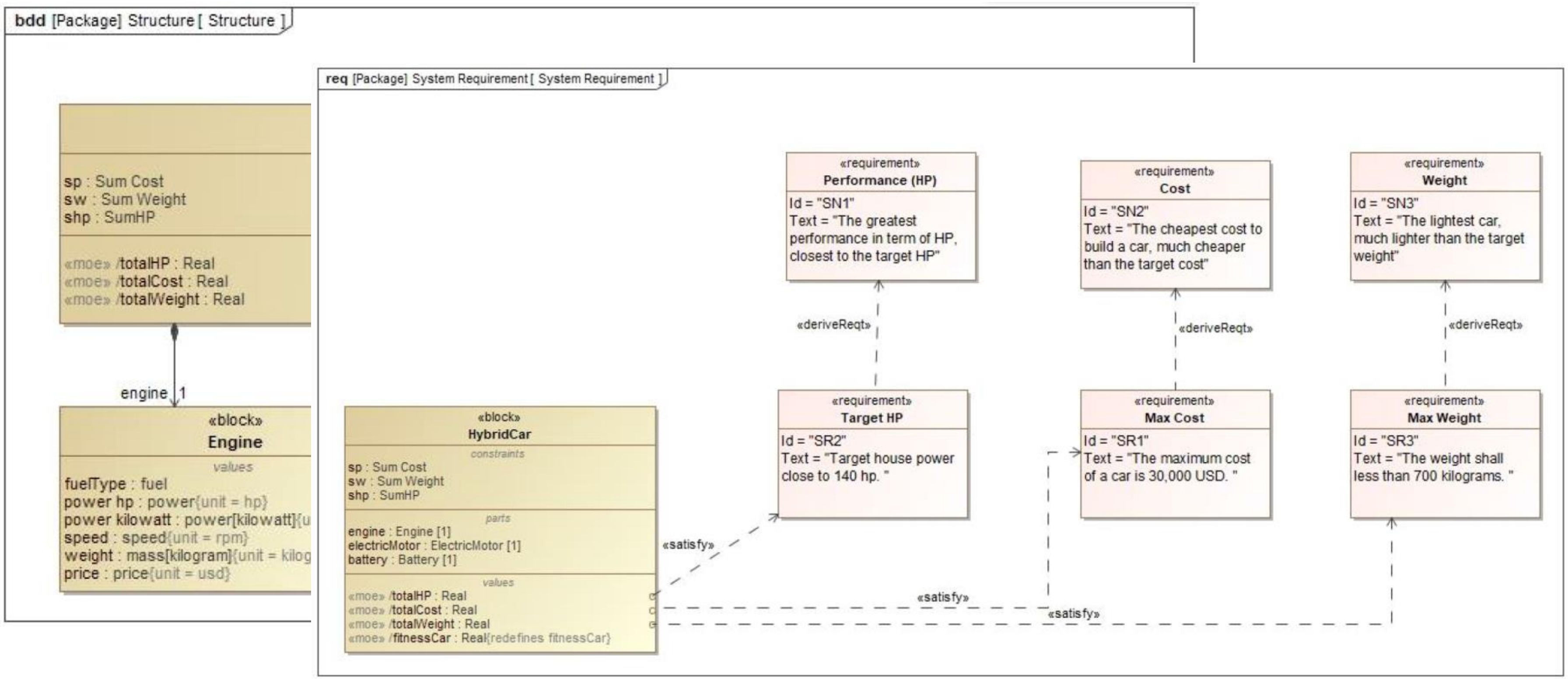
Set Speed
12

p Gain
2.0

speed
9.593438811428…

torque
2406.561188571…

Automated Component Selection



bdd [Package] Structure [Structure]

sp : Sum Cost
sw : Sum Weight
shp : SumHP

«moe» /totalHP : Real
«moe» /totalCost : Real
«moe» /totalWeight : Real

engine 1

«block»
Engine

values
fuelType : fuel
power hp : power{unit = hp}
power kilowatt : power[kilowatt]{u
speed : speed{unit = rpm}
weight : mass[kilogram]{unit = kilog
price : price{unit = usd}

req [Package] System Requirement [System Requirement]

«requirement»
Performance (HP)
Id = "SN1"
Text = "The greatest performance in term of HP, closest to the target HP"

«requirement»
Cost
Id = "SN2"
Text = "The cheapest cost to build a car, much cheaper than the target cost"

«requirement»
Weight
Id = "SN3"
Text = "The lightest car, much lighter than the target weight"

«deriveReqt»

«deriveReqt»

«deriveReqt»

«requirement»
Target HP
Id = "SR2"
Text = "Target house power close to 140 hp. "

«requirement»
Max Cost
Id = "SR1"
Text = "The maximum cost of a car is 30,000 USD. "

«requirement»
Max Weight
Id = "SR3"
Text = "The weight shall less than 700 kilograms. "

«block»
HybridCar

constraints
sp : Sum Cost
sw : Sum Weight
shp : SumHP

parts
engine : Engine [1]
electricMotor : ElectricMotor [1]
battery : Battery [1]

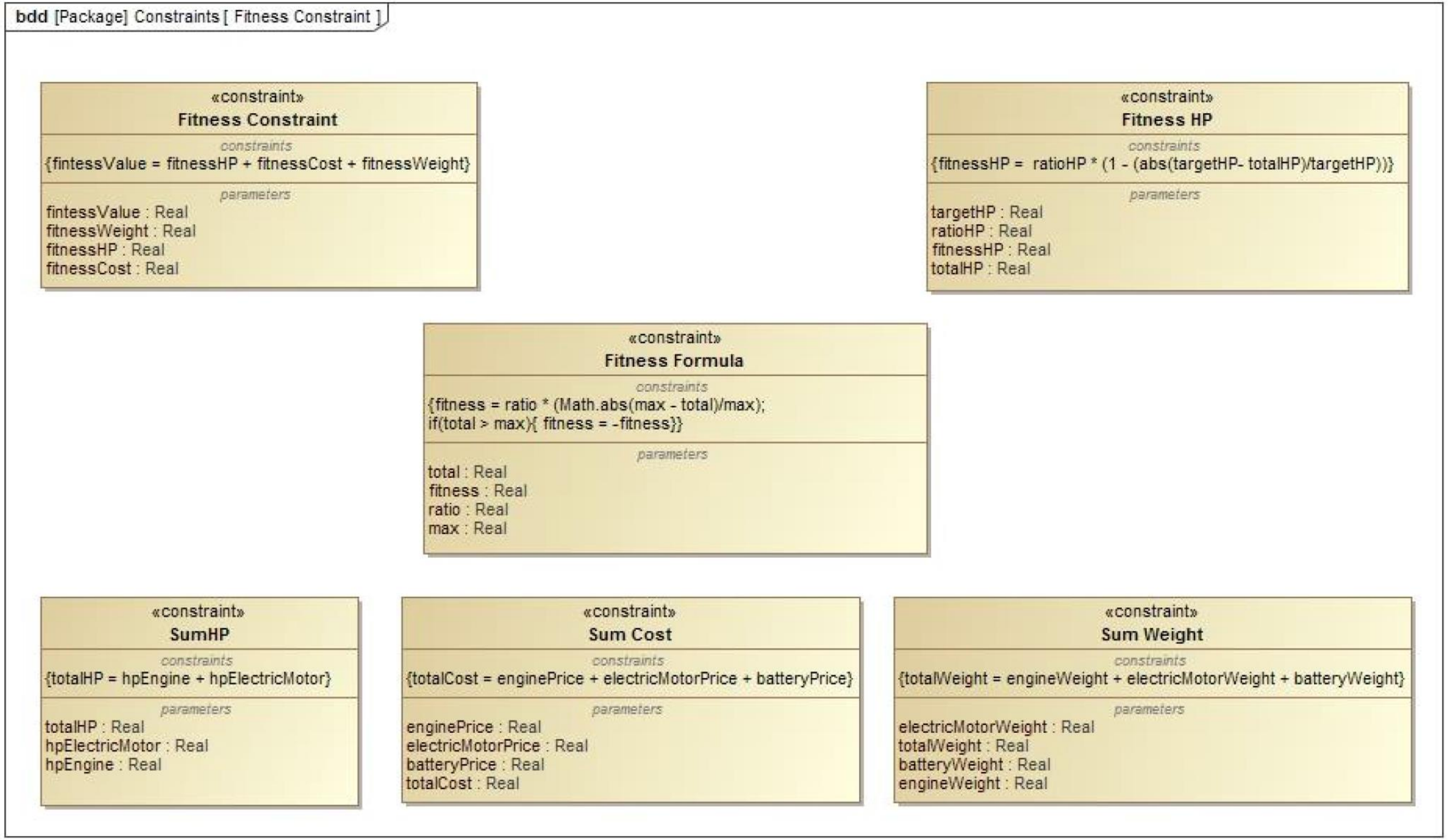
values
«moe» /totalHP : Real
«moe» /totalCost : Real
«moe» /totalWeight : Real
«moe» /fitnessCar : Real{redefines fitnessCar}

«satisfy»

«satisfy»

«satisfy»

Requirements	Value	Weighted Ratio
Target HP	140 hp	0.7
Maximum Cost		
Maximum Weight		



bdd [Package] Constraints [Fitness Constraint]

«constraint»
Fitness Constraint
constraints
{fintessValue = fitnessHP + fitnessCost + fitnessWeight}
parameters
fintessValue : Real
fitnessWeight : Real
fitnessHP : Real
fitnessCost : Real

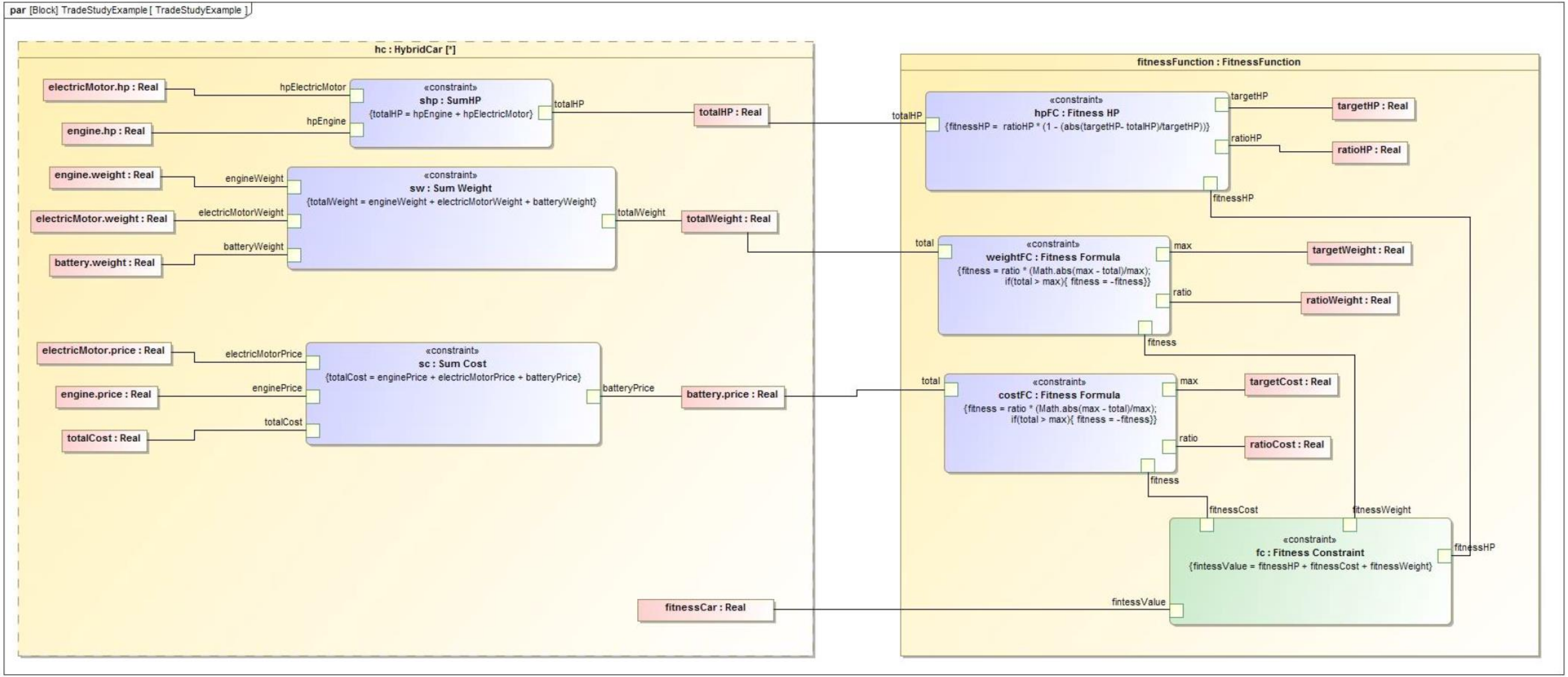
«constraint»
Fitness HP
constraints
{fitnessHP = ratioHP * (1 - (abs(targetHP- totalHP)/targetHP))}
parameters
targetHP : Real
ratioHP : Real
fitnessHP : Real
totalHP : Real

«constraint»
Fitness Formula
constraints
{fitness = ratio * (Math.abs(max - total)/max);
if(total > max){ fitness = -fitness}}
parameters
total : Real
fitness : Real
ratio : Real
max : Real

«constraint»
SumHP
constraints
{totalHP = hpEngine + hpElectricMotor}
parameters
totalHP : Real
hpElectricMotor : Real
hpEngine : Real

«constraint»
Sum Cost
constraints
{totalCost = enginePrice + electricMotorPrice + batteryPrice}
parameters
enginePrice : Real
electricMotorPrice : Real
batteryPrice : Real
totalCost : Real

«constraint»
Sum Weight
constraints
{totalWeight = engineWeight + electricMotorWeight + batteryWeight}
parameters
electricMotorWeight : Real
totalWeight : Real
batteryWeight : Real
engineWeight : Real



par [Block] TradeStudyExample [TradeStudyExample]

hc : HybridCar [*]

electricMotor.hp : Real

engine.hp : Real

hpElectricMotor

hpEngine

«constraint»
shp : SumHP
{totalHP = hpEngine + hpElectricMotor}

totalHP

totalHP : Real

engine.weight : Real

electricMotor.weight : Real

battery.weight : Real

engineWeight

electricMotorWeight

batteryWeight

«constraint»
sw : Sum Weight
{totalWeight = engineWeight + electricMotorWeight + batteryWeight}

totalWeight

totalWeight : Real

electricMotor.price : Real

engine.price : Real

totalCost : Real

electricMotorPrice

enginePrice

totalCost

«constraint»
sc : Sum Cost
{totalCost = enginePrice + electricMotorPrice + batteryPrice}

batteryPrice

battery.price : Real

fitnessCar : Real

fitnessFunction : FitnessFunction

totalHP

«constraint»
hpFC : Fitness HP
{fitnessHP = ratioHP * (1 - (abs(targetHP- totalHP)/targetHP))}

targetHP

targetHP : Real

ratioHP

ratioHP : Real

fitnessHP

total

«constraint»
weightFC : Fitness Formula
{fitness = ratio * (Math.abs(max - total)/max);
if(total > max){ fitness = -fitness}}

max

targetWeight : Real

ratio

ratioWeight : Real

fitness

total

«constraint»
costFC : Fitness Formula
{fitness = ratio * (Math.abs(max - total)/max);
if(total > max){ fitness = -fitness}}

max

targetCost : Real

ratio

ratioCost : Real

fitness

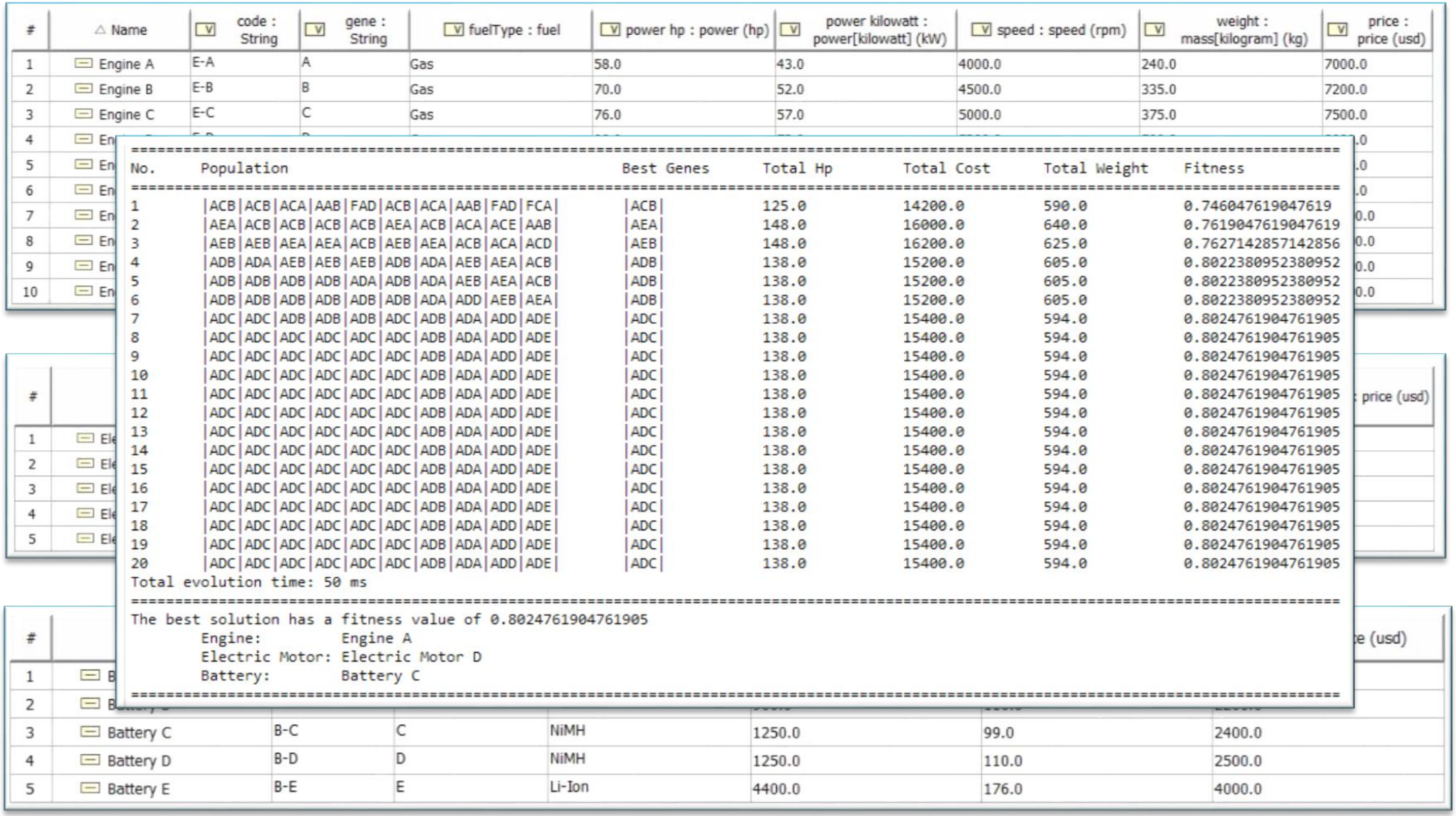
fitnessCost

fitnessWeight

«constraint»
fc : Fitness Constraint
{fintessValue = fitnessHP + fitnessCost + fitnessWeight}

fitnessHP

fintessValue



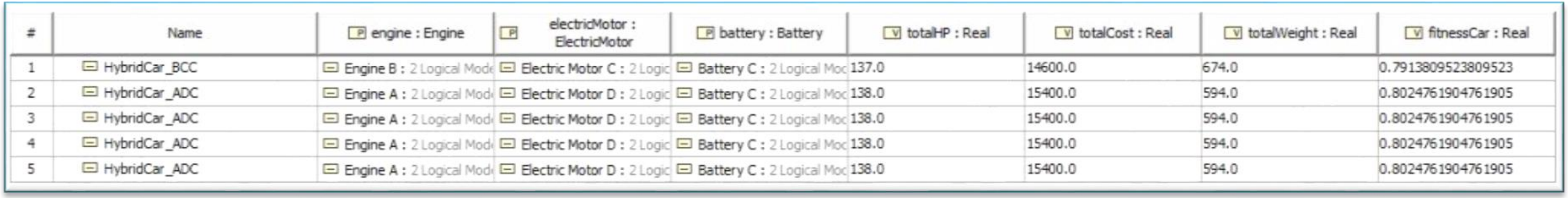
#	Name	code : String	gene : String	fuelType : fuel	power hp : power (hp)	power kilowatt : power[kilowatt] (kW)	speed : speed (rpm)	weight : mass[kilogram] (kg)	price : price (usd)
1	Engine A	E-A	A	Gas	58.0	43.0	4000.0	240.0	7000.0
2	Engine B	E-B	B	Gas	70.0	52.0	4500.0	335.0	7200.0
3	Engine C	E-C	C	Gas	76.0	57.0	5000.0	375.0	7500.0
4	En								.0
5	En								.0
6	En								.0
7	En								0.0
8	En								0.0
9	En								0.0
10	En								0.0

```
===========================================================================================================
No.     Population                              Best Genes   Total Hp     Total Cost    Total Weight  Fitness
===========================================================================================================
1       |ACB|ACB|ACA|AAB|FAD|ACB|ACA|AAB|FAD|FCA|     |ACB|        125.0        14200.0       590.0         0.746047619047619
2       |AEA|ACB|ACB|ACB|ACB|AEA|ACB|ACA|ACE|AAB|     |AEA|        148.0        16000.0       640.0         0.7619047619047619
3       |AEB|AEB|AEA|AEA|ACB|AEB|AEA|ACB|ACA|ACD|     |AEB|        148.0        16200.0       625.0         0.7627142857142856
4       |ADB|ADA|AEB|AEB|AEB|ADB|ADA|AEB|AEA|ACB|     |ADB|        138.0        15200.0       605.0         0.8022380952380952
5       |ADB|ADB|ADB|ADB|ADA|ADB|ADA|AEB|AEA|ACB|     |ADB|        138.0        15200.0       605.0         0.8022380952380952
6       |ADB|ADB|ADB|ADB|ADB|ADB|ADA|ADD|AEB|AEA|     |ADB|        138.0        15200.0       605.0         0.8022380952380952
7       |ADC|ADC|ADB|ADB|ADB|ADC|ADB|ADA|ADD|ADE|     |ADC|        138.0        15400.0       594.0         0.8024761904761905
8       |ADC|ADC|ADC|ADC|ADC|ADC|ADB|ADA|ADD|ADE|     |ADC|        138.0        15400.0       594.0         0.8024761904761905
9       |ADC|ADC|ADC|ADC|ADC|ADC|ADB|ADA|ADD|ADE|     |ADC|        138.0        15400.0       594.0         0.8024761904761905
10      |ADC|ADC|ADC|ADC|ADC|ADC|ADB|ADA|ADD|ADE|     |ADC|        138.0        15400.0       594.0         0.8024761904761905
11      |ADC|ADC|ADC|ADC|ADC|ADC|ADB|ADA|ADD|ADE|     |ADC|        138.0        15400.0       594.0         0.8024761904761905
12      |ADC|ADC|ADC|ADC|ADC|ADC|ADB|ADA|ADD|ADE|     |ADC|        138.0        15400.0       594.0         0.8024761904761905
13      |ADC|ADC|ADC|ADC|ADC|ADC|ADB|ADA|ADD|ADE|     |ADC|        138.0        15400.0       594.0         0.8024761904761905
14      |ADC|ADC|ADC|ADC|ADC|ADC|ADB|ADA|ADD|ADE|     |ADC|        138.0        15400.0       594.0         0.8024761904761905
15      |ADC|ADC|ADC|ADC|ADC|ADC|ADB|ADA|ADD|ADE|     |ADC|        138.0        15400.0       594.0         0.8024761904761905
16      |ADC|ADC|ADC|ADC|ADC|ADC|ADB|ADA|ADD|ADE|     |ADC|        138.0        15400.0       594.0         0.8024761904761905
17      |ADC|ADC|ADC|ADC|ADC|ADC|ADB|ADA|ADD|ADE|     |ADC|        138.0        15400.0       594.0         0.8024761904761905
18      |ADC|ADC|ADC|ADC|ADC|ADC|ADB|ADA|ADD|ADE|     |ADC|        138.0        15400.0       594.0         0.8024761904761905
19      |ADC|ADC|ADC|ADC|ADC|ADC|ADB|ADA|ADD|ADE|     |ADC|        138.0        15400.0       594.0         0.8024761904761905
20      |ADC|ADC|ADC|ADC|ADC|ADC|ADB|ADA|ADD|ADE|     |ADC|        138.0        15400.0       594.0         0.8024761904761905
Total evolution time: 50 ms
===========================================================================================================
The best solution has a fitness value of 0.8024761904761905
        Engine:         Engine A
        Electric Motor: Electric Motor D
        Battery:        Battery C
===========================================================================================================
```

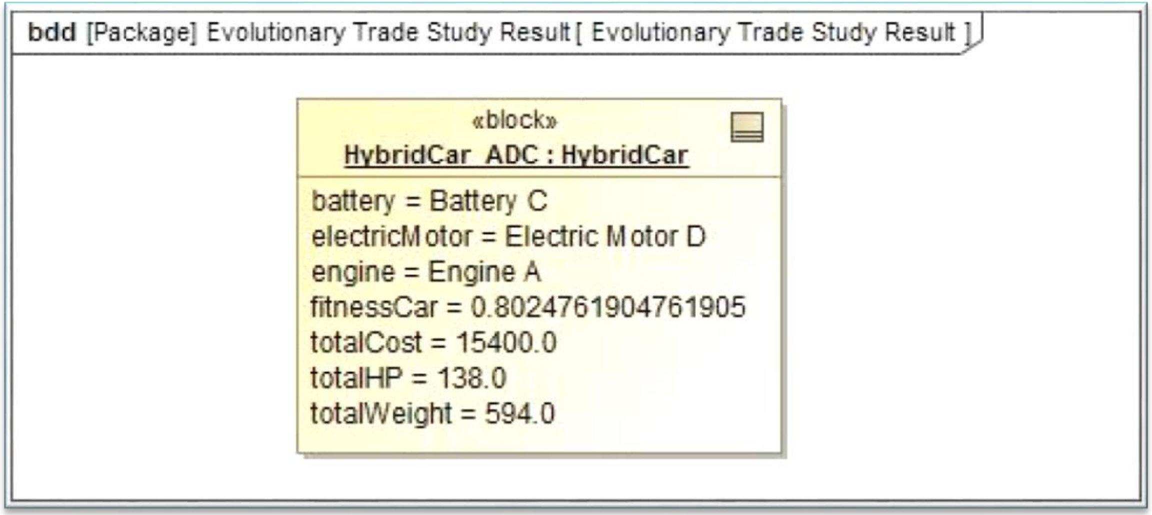
#		: price (usd)
1	Ele	
2	Ele	
3	Ele	
4	Ele	
5	Ele	

#							e (usd)
1	B						
2	B						
3	Battery C	B-C	C	NiMH	1250.0	99.0	2400.0
4	Battery D	B-D	D	NiMH	1250.0	110.0	2500.0
5	Battery E	B-E	E	Li-Ion	4400.0	176.0	4000.0

And the winner is…



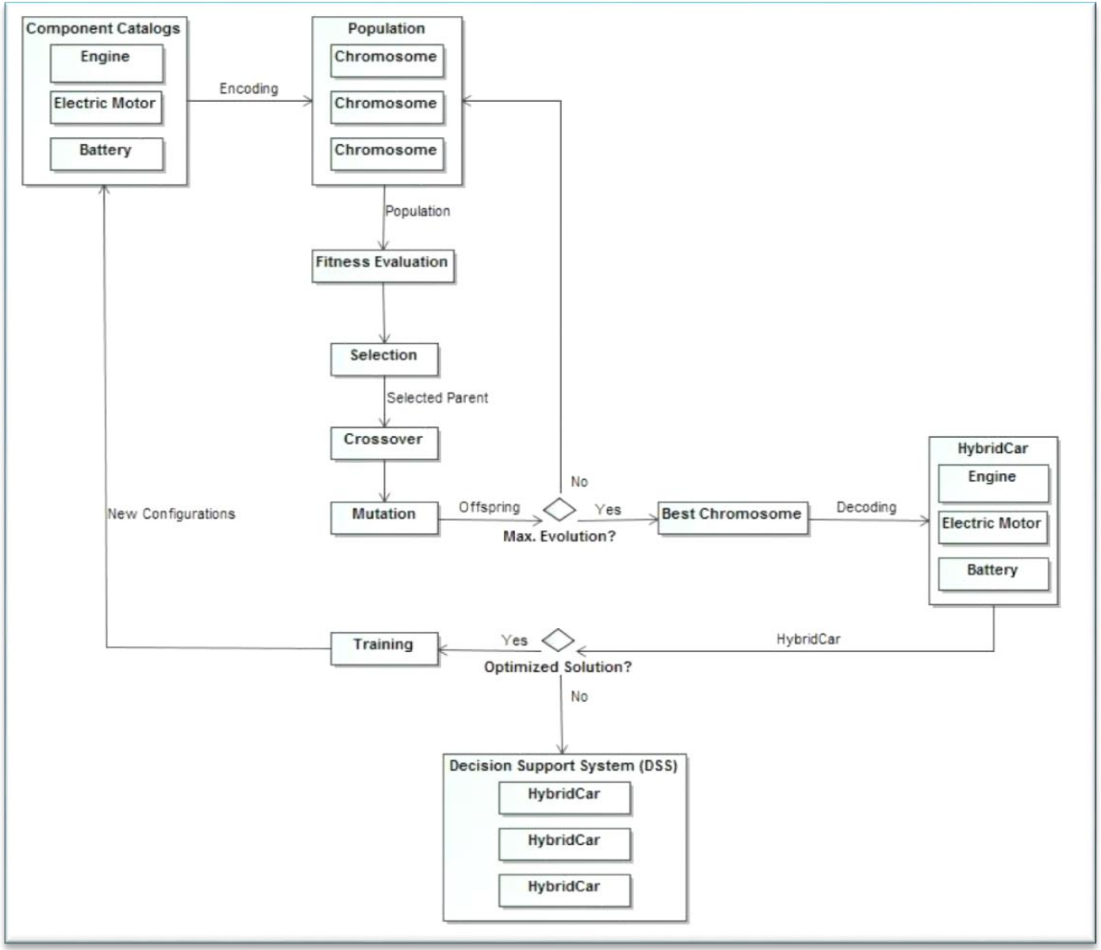
#	Name	engine : Engine	electricMotor : ElectricMotor	battery : Battery	totalHP : Real	totalCost : Real	totalWeight : Real	fitnessCar : Real
1	HybridCar_BCC	Engine B : 2 Logical Mode	Electric Motor C : 2 Logic	Battery C : 2 Logical Moc	137.0	14600.0	674.0	0.7913809523809523
2	HybridCar_ADC	Engine A : 2 Logical Mod	Electric Motor D : 2 Logic	Battery C : 2 Logical Moc	138.0	15400.0	594.0	0.8024761904761905
3	HybridCar_ADC	Engine A : 2 Logical Mod	Electric Motor D : 2 Logic	Battery C : 2 Logical Moc	138.0	15400.0	594.0	0.8024761904761905
4	HybridCar_ADC	Engine A : 2 Logical Mod	Electric Motor D : 2 Logic	Battery C : 2 Logical Moc	138.0	15400.0	594.0	0.8024761904761905
5	HybridCar_ADC	Engine A : 2 Logical Mod	Electric Motor D : 2 Logic	Battery C : 2 Logical Moc	138.0	15400.0	594.0	0.8024761904761905



bdd [Package] Evolutionary Trade Study Result [Evolutionary Trade Study Result]

«block»
HybridCar_ADC : HybridCar

battery = Battery C
electricMotor = Electric Motor D
engine = Engine A
fitnessCar = 0.8024761904761905
totalCost = 15400.0
totalHP = 138.0
totalWeight = 594.0


Component Catalogs
Engine
Electric Motor
Battery
Encoding
Population
Chromosome
Chromosome
Chromosome
Population
Fitness Evaluation
Selection
Selected Parent
Crossover
Mutation
Offspring
No
Yes
Max. Evolution?
Best Chromosome
Decoding
HybridCar
Engine
Electric Motor
Battery
New Configurations
HybridCar
Training
Yes
Optimized Solution?
No
Decision Support System (DSS)
HybridCar
HybridCar
HybridCar

Summary

- MBSE simplifies complexity
- Promotes consistent communication through use of a common notation and a single source of truth
- Provides rigor and discipline to system design and optimization
- Future is in assisted design
- It is not a silver bullet
  - Takes time to implement and fully realize the benefits
  - Requires commitment to developing a modeling practice
  - Benefits from development of corporate standards and reusable libraries

Thank You!

Enrique Krajmalnik
CTO
enrique@nomagic.com

Moy Speckman
VP, Worldwide Sales
mspeckman@nomagic.com

NMWS2018
May 20 – 23, Allen TX

http://www.nomagic.com