Model-Based Product Line Engineering with Genetic Algorithms for Automated Component Selection

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Product Line Engineering (PLE) Concept

- Product Line

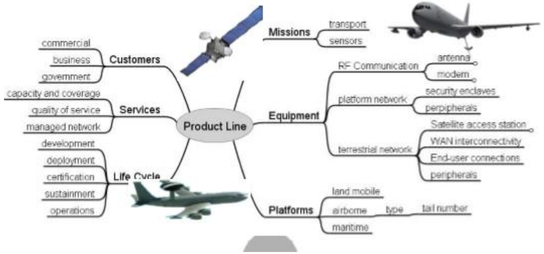
  A family of similar products with variations in features and functions.

- Product Line Engineering

  The engineering of a product line using a shared set of engineering assets, a managed set of features, and an efficient means of production …

- Taking advantage of the commonality shared across the family
- Efficiently and systematically managing the variation among the products

http://productlineengineering.com

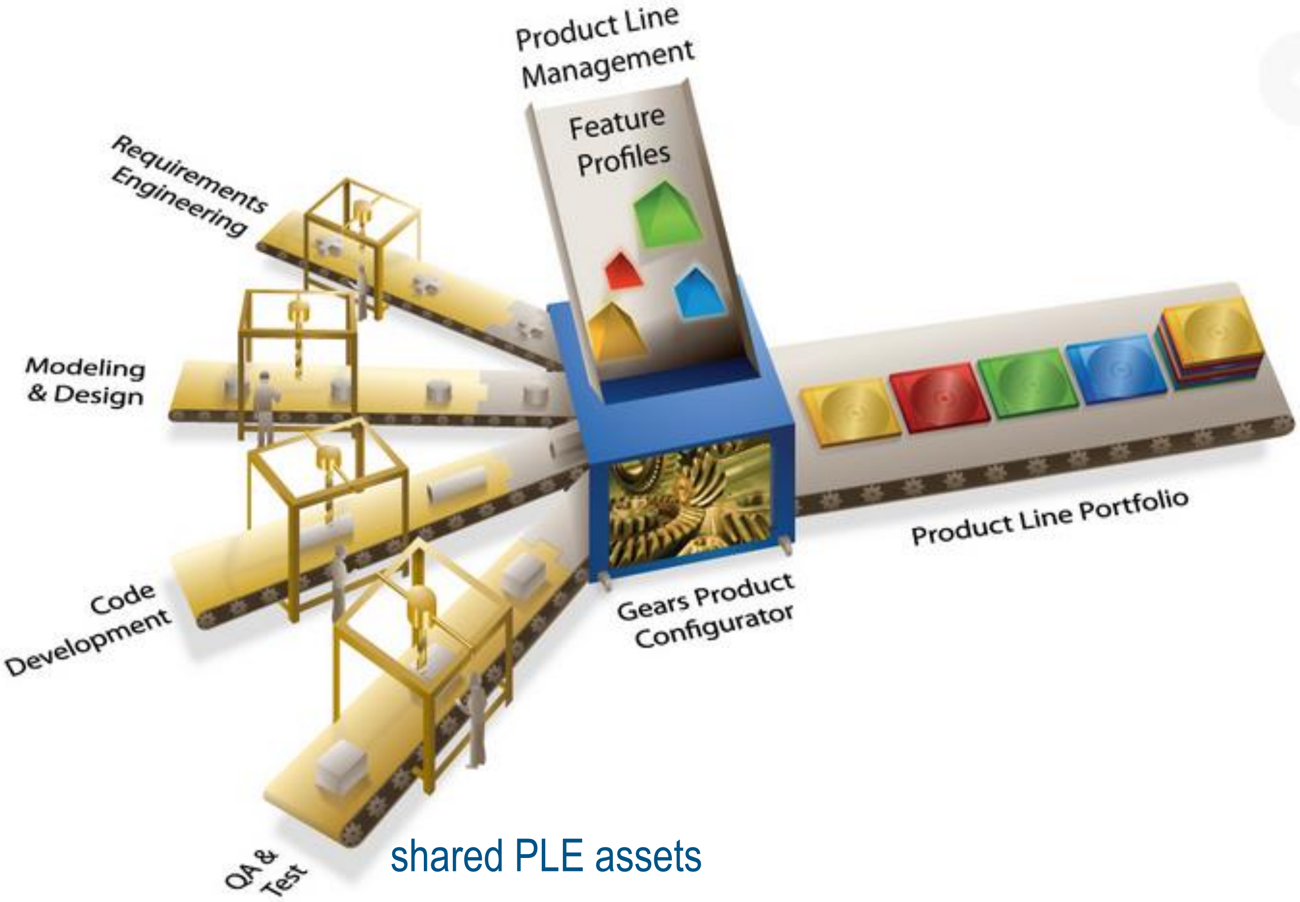


Why is PLE Important?

PLE is important because organizations that practice it are experiencing remarkable strategic business and technical benefits. Examples of benefits include faster time to market (up to 10x), reduced cost for building and delivering a product (up to 10x), increased product line scalability (up to 5x), and increased product quality (up to 10x).

DASSAULT SYSTEMES

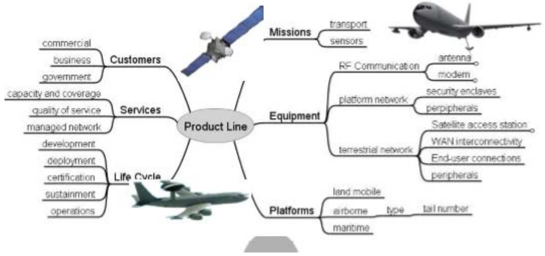
PLE workflow



shared PLE assets

Product Line Engineering Challenge

- The rise of systems **complexity**, high and increasing needs of the variety of product lines, customized products, or different designs for trade study analysis.
- Develop a complex system at a **lower cost and shorter time-to-market**.
- Opportunistic, isolated reuse (copy paste) and high non-recurring engineering
- Concurrent engineering and knowledge transfer
- An increasing number of possible features in a feature model and quantity of variation points in a system model can increase the dimension of solution space. Manually trade off is time and cost consuming and error-prone.



Solution to the challenge

MBPLE with genetic algorithm (GA)

- Allow users to model product lines in industry standard or de facto standard formats.
- Optimizing system architectures, performing trade-off studies, performing verification & validation, and promoting the development of cohesive operational, functional and physical architectures of the system.
- Helping establish meta-model consistency and traceability of the different engineering artefacts
- Automation in the component selection of design synthesis in MBSE

Content

Methodology

Building 150% Model with MBPLE and Producing 100% Model

1. Building Feature Model
2. Building 150% Model with Variation Point and Feature Impact
3. Define Variant Configuration
4. Producing 100% Model with Variant Realization

Selecting Components for 100% Model with Genetic Algorithms

1. Encode 100% Model to Chromosome
2. Create Alternative solution
3. Fitness evaluation
4. Get best solution

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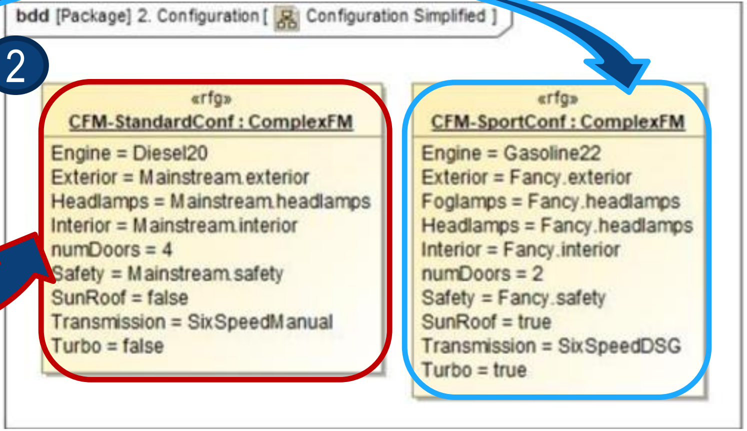
Feature Model and Configurations

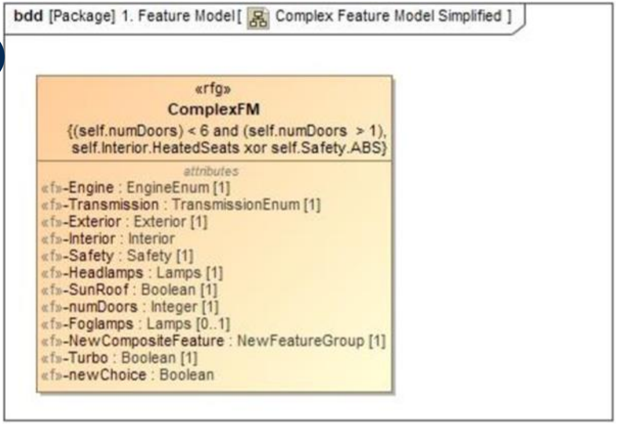
No.	Feature	*StandardCar*	*SportCar*
1	Engine	TurboDiesel	AtmoGasoline
2	Chassis	Exist	Exist
3	Wheel	Exist	Exist
4	SunRoof	Not Exist	Exist
5	Spoiler	Not Exist	Exist
6	Lamp	Exist	Exist
7	FilementBurnoutDetector	Exist	Exist
8	AutolevelingMotor	Not Exist	Exist
9	Door	4 Doors	2 Doors

2



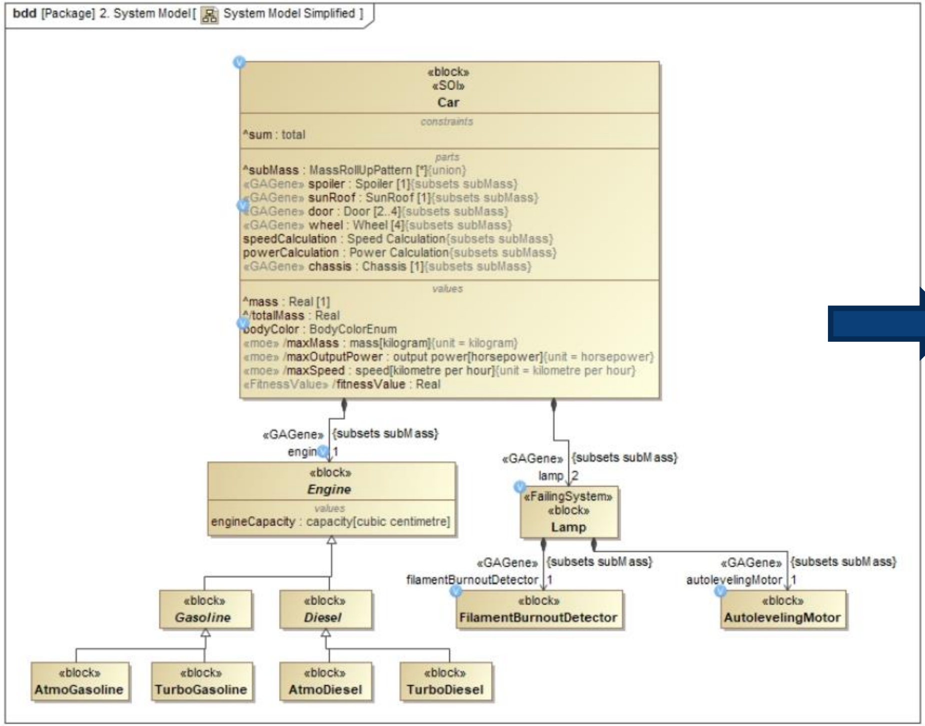
Example of Configuration Defined

1

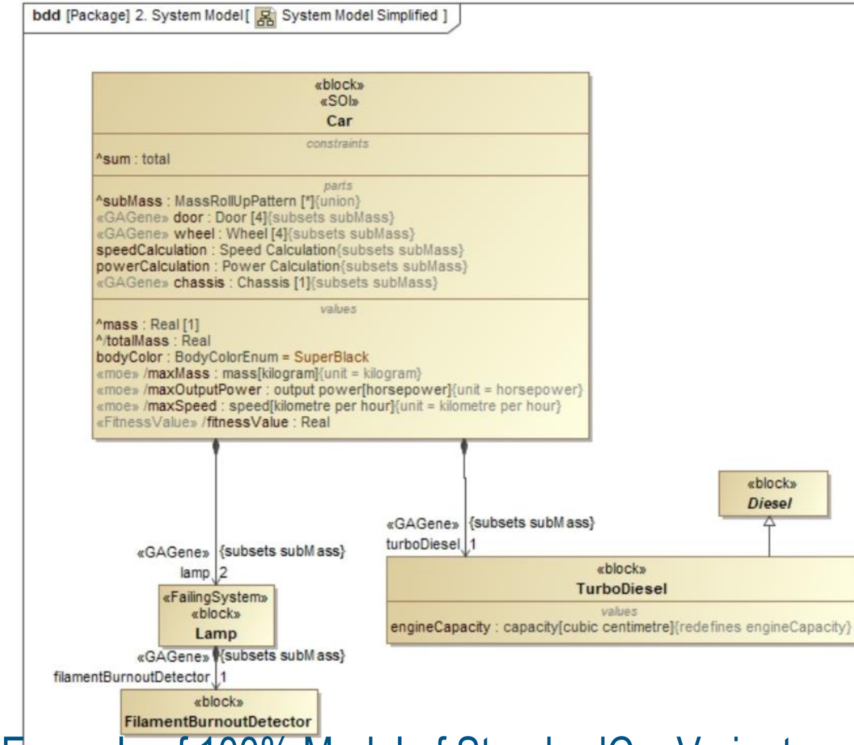


Example of Feature Model

Completed 150% Model to 100% system Model

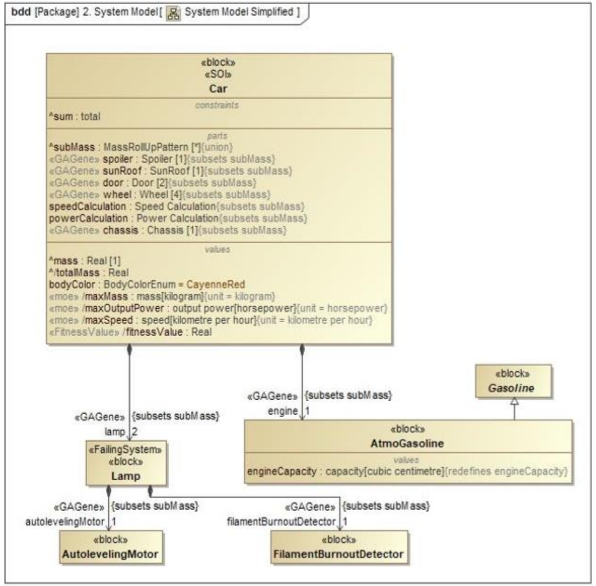


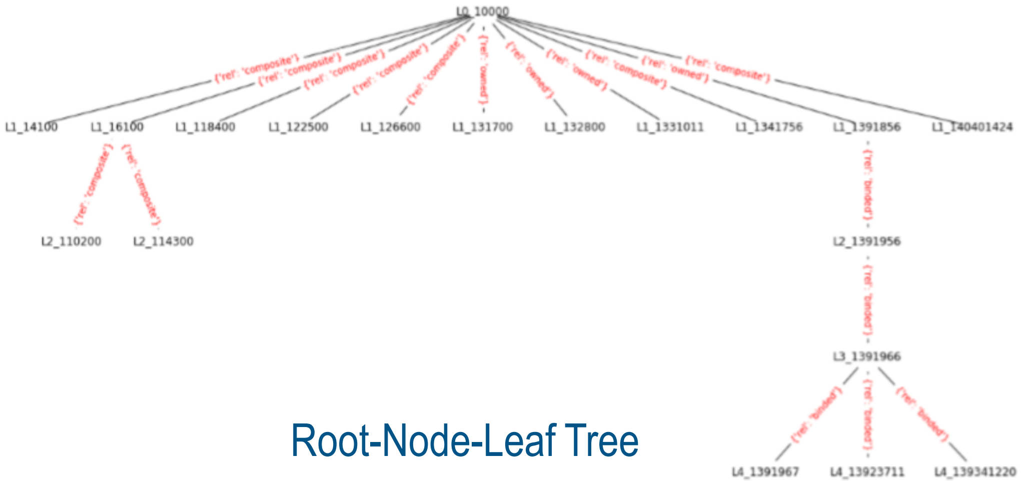
150% Model with Variation Point



Example of 100% Model of StandardCar Variant

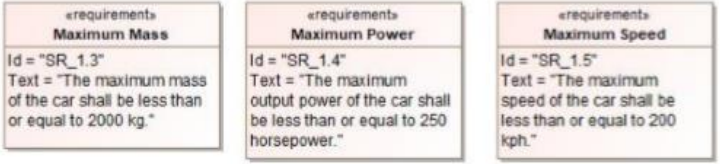
100% system model with RNL tree encoding

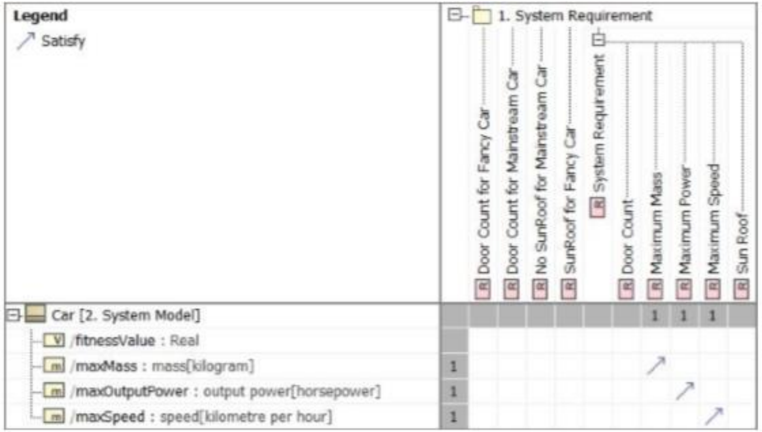




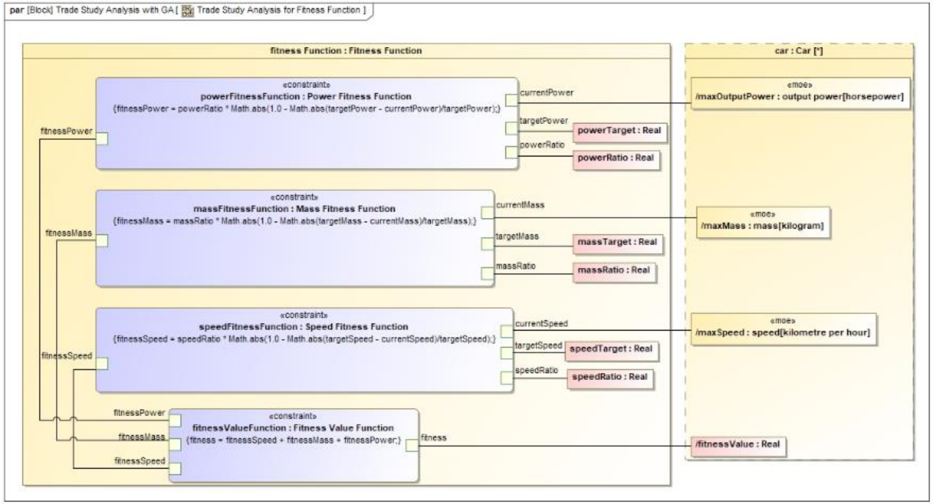
Root-Node-Leaf Tree

Fitness Function derived from requirements



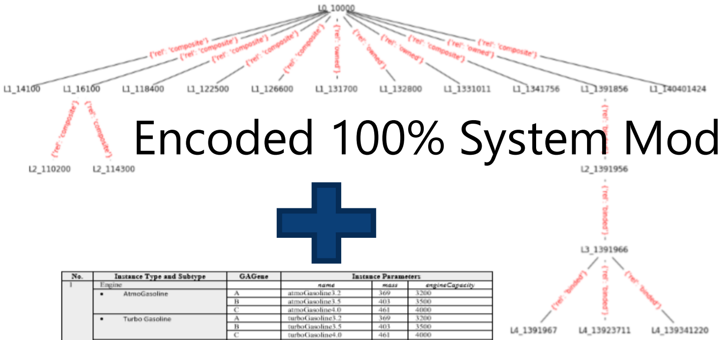


Satisfy MOEs to Requirements



Parametric Diagram of Fitness Function

Result of automatic components selection



Encoded 100% System Model

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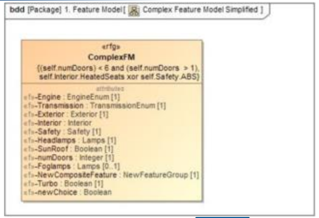
No.	Instance Type and Subtype	GAGene	Instance Parameters		
1	Engine		*name*	*mass*	*engineCapacity*
	• AtmoGasoline	A	atmoGasoline3.2	369	3200
		B	atmoGasoline3.5	403	3500
		C	atmoGasoline4.0	461	4000
	• Turbo Gasoline	A	turboGasoline3.2	369	3200
		B	turboGasoline3.5	403	3500
		C	turboGasoline4.0	461	4000
	• AtmoDiesel	A	atmoDiesel2.4	272	2362
		B	atmoDiesel2.8	327	2835
		C	atmoDiesel3.2	369	3200
	• TurboDiesel	A	turboDiesel2.4	272	2362
		B	turboDiesel2.8	327	2835
		C	turboDiesel3.2	369	3200
2	Chassis		*name*	*mass*	
		A	chassisA	1000	
		B	chassisB	1250	
		C	chassisC	1500	
3	Wheel		*name*	*mass*	*diameter*
		A	wheel17inc	8	43.18
		B	wheel18inc	8.47	45.72
		C	wheel19inc	8.94	48.26
		D	wheel20inc	9.41	50.8
		E	wheel21inc	9.88	53.34
		F	wheel22inc	10.4	55.88
		G	wheel23inc	10.8	58.42
		H	wheel24inc	11.3	60.96
4	SunRoof		*name*	*mass*	
		A	sunRoofA	54.4	
		B	sunRoofB	63.5	
		C	sunRoofC	72.6	
		D	sunRoofD	81.7	
		E	sunRoofE	90.7	
5	Spoiler		*name*	*mass*	
		A	spoilerA	5.44	
		B	spoilerB	6.35	
		C	spoilerC	7.26	
		D	spoilerD	8.16	
		E	spoilerE	9.07	
6	Lamp		*name*	*mass*	
		A	lampA	4.99	
		B	lampB	5.44	
		C	lampC	5.9	
		D	lampD	6.35	
		E	lampE	6.8	
7	FilementBurnoutDetector		*name*	*mass*	
		A	filamentA	0.27	
		B	filamentB	0.32	
		C	filamentC	0.36	
		D	filamentD	0.41	
		E	filamentE	0.45	
8	AutolevelingMotor		*name*	*mass*	
		A	autoA	2.27	
		B	autoB	2.72	
		C	autoC	3.18	
		D	autoD	3.63	
		E	autoE	4.08	
9	Door		*name*	*mass*	
		A	doorA	54.4	
		B	doorB	59	
		C	doorC	63.5	
		D	doorD	68	
		E	doorE	72.6	

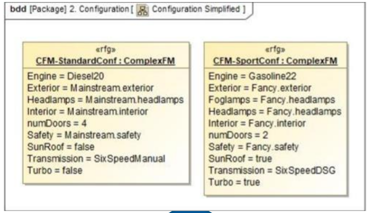
BOM (Bill of Materials)

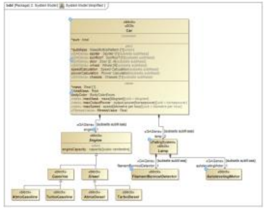
Fitness evaluation

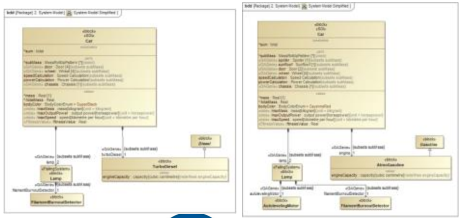
Chromosome	MOE			Fitness Value
	maxMass(kilogram)	*maxOutputPower(hp)*	*maxSpeed(kilometers per hour)*	
['B', 'A', 'B', 'B', 'C', 'B', 'D', 'C', 'C']	1755.62	250	151.0973307695852	0.853305326923963
['B', 'C', 'C', 'B', 'B', 'D', 'A', 'D', 'C']	1749.38	250	151.2767712040366	0.8531299280100915
['B', 'A', 'A', 'A', 'C', 'B', 'A', 'A', 'C']	1724.14	250	152.01138747111003	0.852442468677775
['B', 'A', 'B', 'B', 'A', 'B', 'A', 'A', 'C']	1722.82	250	152.05020054249442	0.852407501356236
['B', 'C', 'A', 'C', 'C', 'C', 'B', 'B', 'A']	1246.9	250	169.3517766866317	0.8480694417165793

Example at a glance









1 Feature Model

2 Define recorded configurations

3 Model 150% Model

4 Variant realization transformation
Get 100% system Model

5 Fitness Function derived from requirements

6 100% system model with RNL tree encoding

7 Fitness evaluation

8 Result
Get best solution

Chromosome	MOE			Fitness Value
	maxMass(kilogram)	*maxOutputPower(hp)*	*maxSpeed(kilometers per hour)*	
['B', 'A', 'B', 'B', 'C', 'B', 'D', 'C', 'C']	1755.62	250	151.0973307695852	0.853305326923963
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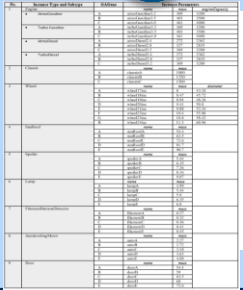

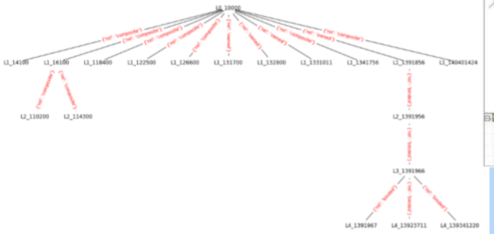

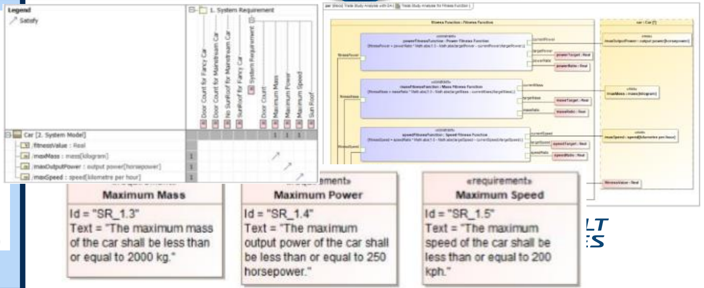

Take away

- GA is not only solution for optimization problems. This paper shows **how to connect system model and optimizations algorithms** through knowledge abstraction from system model with encoding and decoding.
- The examples of the other optimization algorithms that can be extended from this paper is Pareto NSGA-II
- The most important point in optimization or searching problem in system engineering (MBPLE) is **how we extract knowledge from system model or system design including requirement, design, coding, constraints, formula**…

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