Complexity Assessment Using SysML

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Complexity Assessment Using SysML

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Overview

1. Motivation
2. Complexity Definition
3. Complexity Metric
4. Case Study
5. Conclusion & Future Work

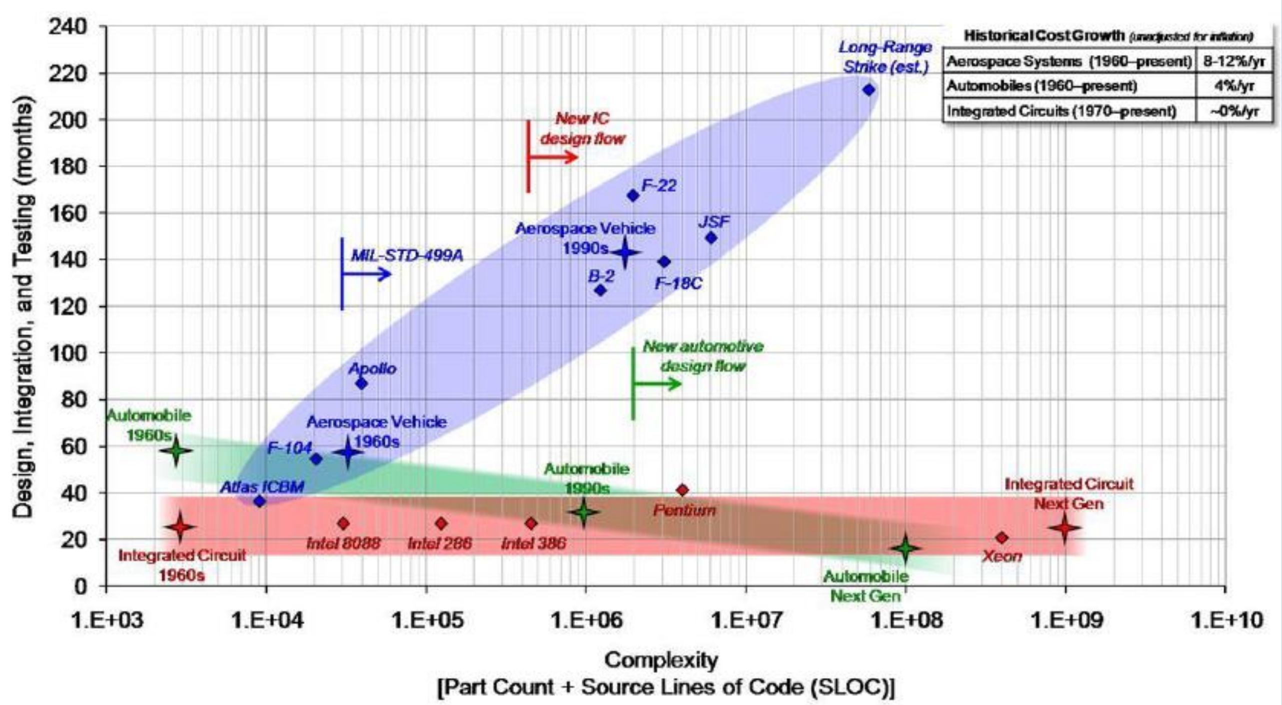
Motivation

Examples of Complexity in the news:

About SLS' Schedule Delay: "*Low monetary reserves limit the programs' flexibility to cover increased costs or delays resulting from* ***unexpected design complexity****, incomplete requirements, or technology uncertainties.".* – NASA (Apr. 2017)

About the F-22: "***We must break the old habit of adding*** *layer upon layer of cost****, complexity*** *and delay to systems that are so expensive and so elaborate that only a small number can be built and are usable in only a narrow range of low-probability scenarios"* - Secretary of Defense Gates (July 2009)

Complexity:



@ Eremenko

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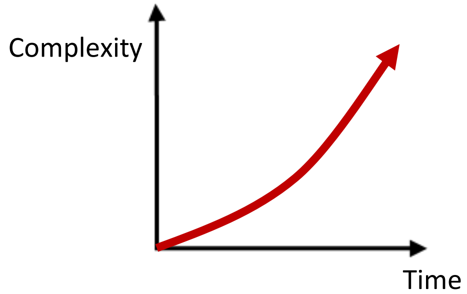
Motivation

General ideas:

- Complexity is associated with problems

Complexity →
- budget overruns
- schedule delays
- system failures
- program cancellation.

- Systems are becoming more complex



How is Complexity managed currently

- No agreed upon definition or working understanding of complexity
- Complexity management is largely done based on intuition and experience
- Existing complexity management techniques are limited:
  - Techniques require a lot of data gathering and manipulation
    - Design Structured Matrix (DSM) and manipulation
  - Techniques are very specialized
    - Requirement analysis, Manufacturing complexity
  - The complexity estimation was conceived for another industry
    - Complexity in Computer science

	A	B	C	D	E	F	G
Element A	A	1				1	
Element B		B		1			
Element C	1		C				1
Element D				D	1		
Element E		1			E	1	
Element F			1			F	
Element G	1				1		G

How to manage complexity more effectively in Systems Development

What is Complexity?

Common Definitions

- Oxford Dictionary

  The state or quality of being intricate or complicated.

- INCOSE

  A measure of how well **knowledge** of a system's component parts explains the system's behavior and also by the **number of mutually interacting and interwoven parts, entities or agents**

- Simon

  A complex system is a system composed of a large **number of parts** that **interact** in a nonsimple way, and that therefore have an **emergent behaviour.**

No agreed upon definition

3 aspects of complexity

- Nonlinearity / Emergence

  The system is more than the sum of its components

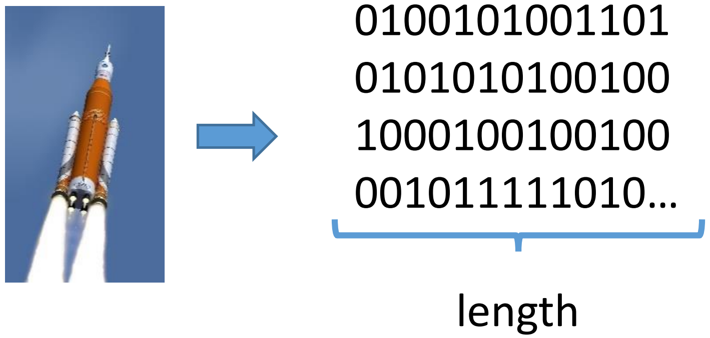
- Difficulty to describe the system

  Associated with the information content of the system

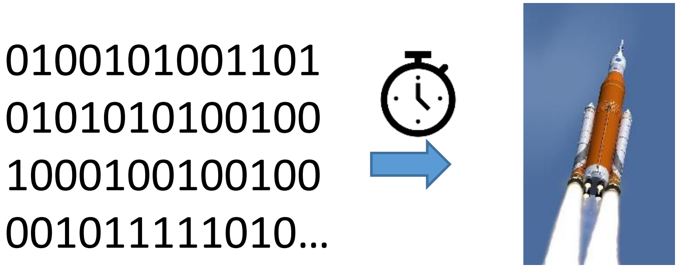
- **Difficulty of creation**

  Difficulty of the process that brought the object into existence

Nonlinearity



Difficulty to describe



Difficulty of creation

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Working definition of complexity

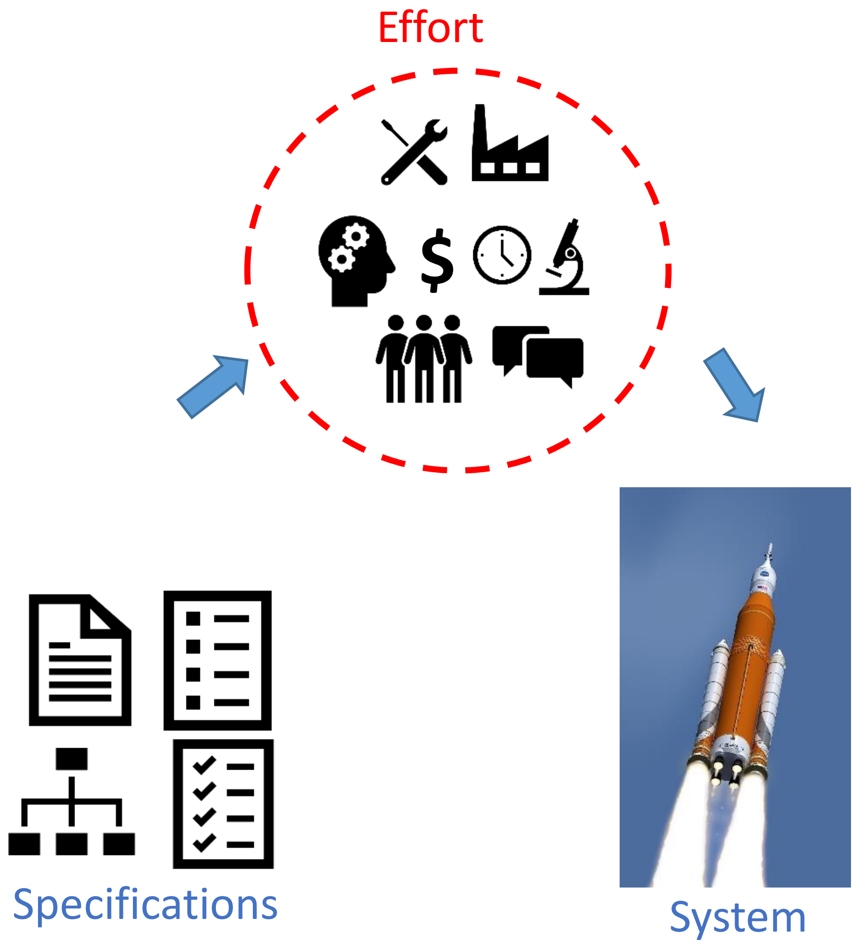
Definition:

"Complexity is the minimum effort required to acquire a system based on the system specifications"

- Where:
  - "effort" is a measure of the resources spent: Time, Money, Labor, Information
- Note
  - Under this understanding an identical object can have different complexity values depending on the resources available, and the allocation of such resources

Factors that contribute to complexity

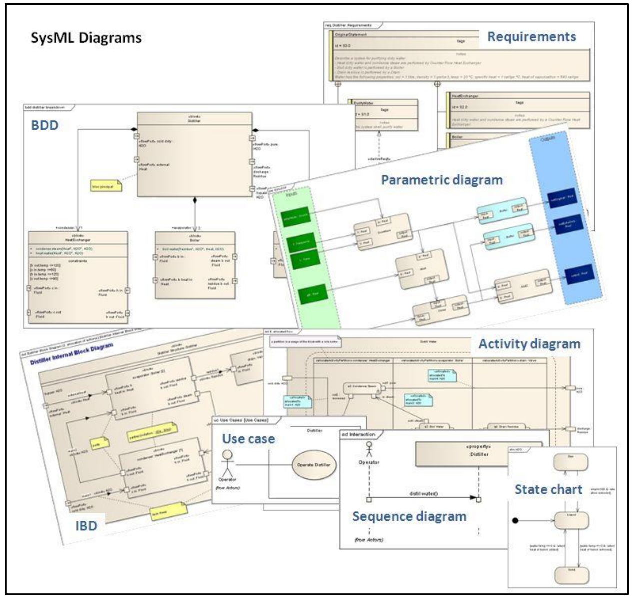
- Size – Number of Components, Number of parts, Number of lines of code
- Interactions – Number of interactions, Type of interactions
- Degree of Organization – Hierarchical organization



Using SysML for the complexity assessment

What is SysML – "Systems Modeling Language"

- Graphical language which uses 9 different types of diagrams to represent a system.
- Extension of UML (Unified Modeling Language) used in software development
- Model Based Systems Engineering (MBSE) often uses SysML
- Used to create models of the system for various purposes. Requirement tracking, physical modeling, Communication, Trade Studies and so on.

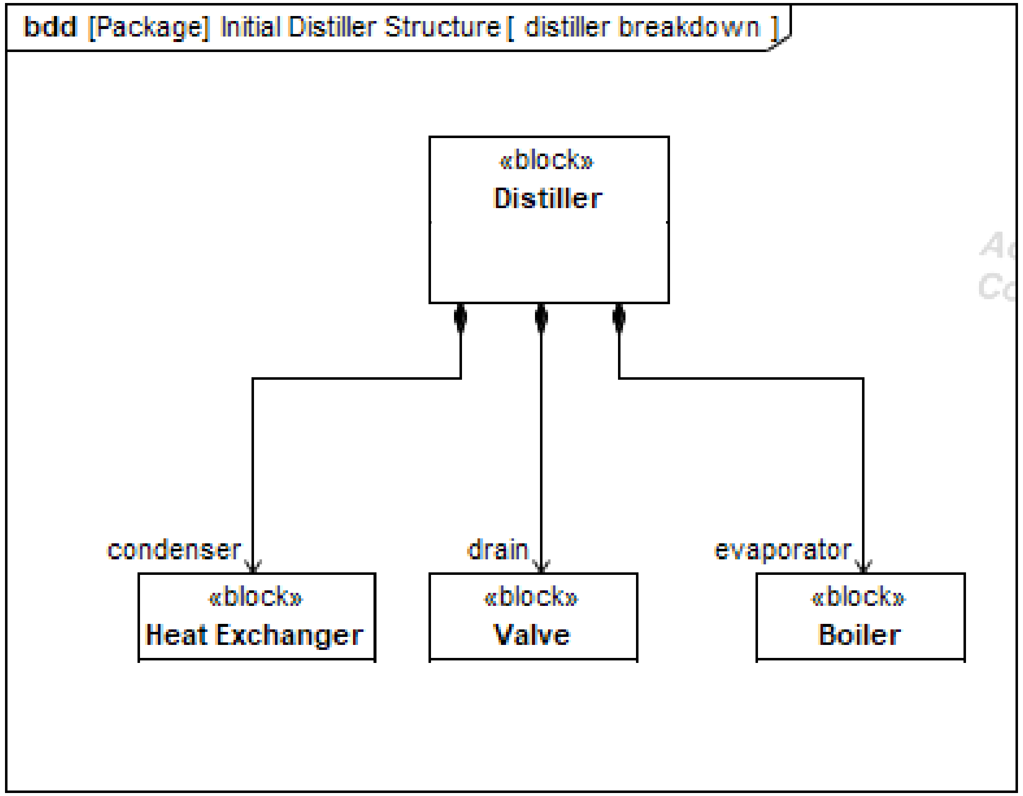


SysML

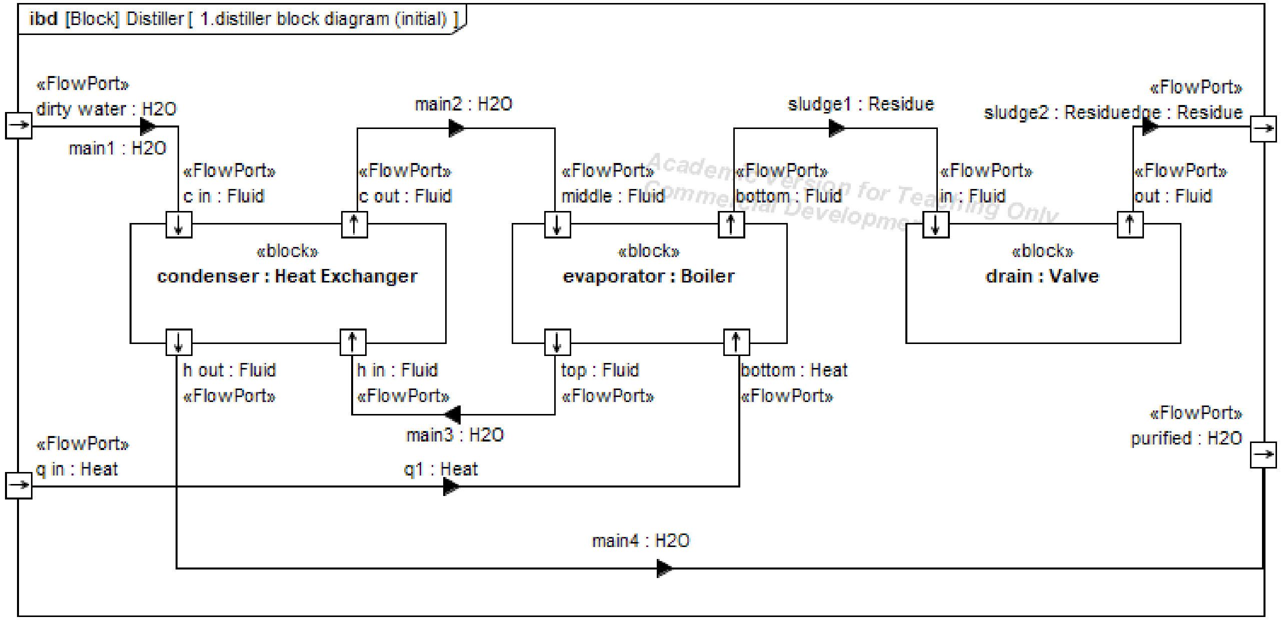
Why use SysML to measure complexity

- SysML models used for other purposes already contain information about the size, interactions and hierarchical organization of the system
- Integrating complexity in the model will allow designers to immediately take into account the impact of their decisions on system complexity
- UML has been useful in managing complexity in software systems developments

SysML diagrams for complexity estimation

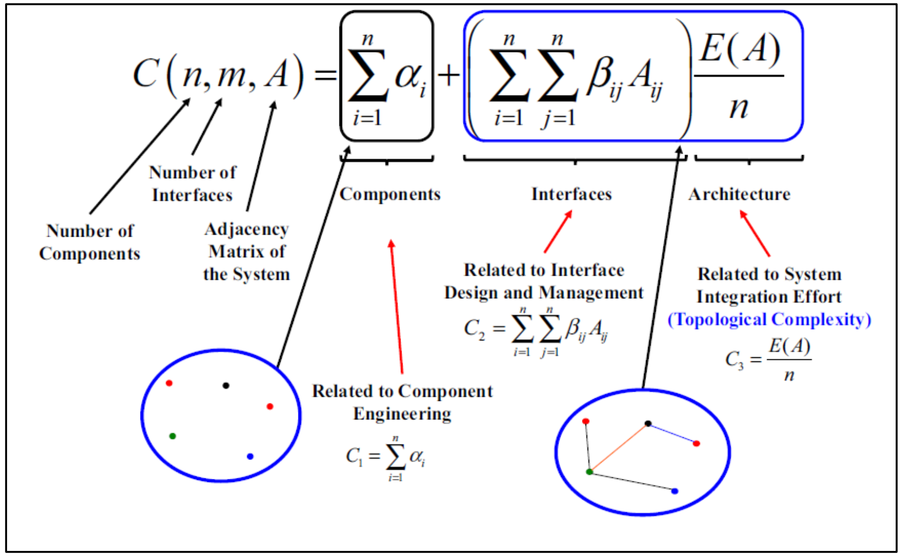


Block Definition Diagram (BDD)



Internal Block Diagram (IBD)

Complexity Metric



@ Sinha and Suh

Complexity Metric of Sinha and Suh:

Adaptations:

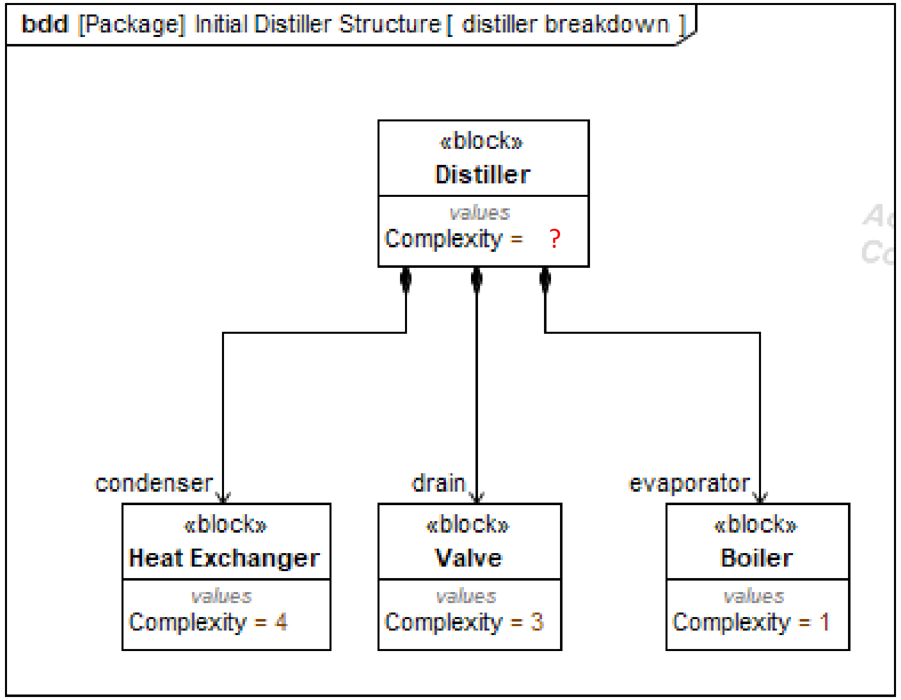
- To account for external interactions
  - Graph Energy replaced by cyclomatic complexity
  - Included a term for external interactions
- To leverage the information available
  - The interaction complexity is directly determined based on the information available about the interactions without having to build an adjacency matrix

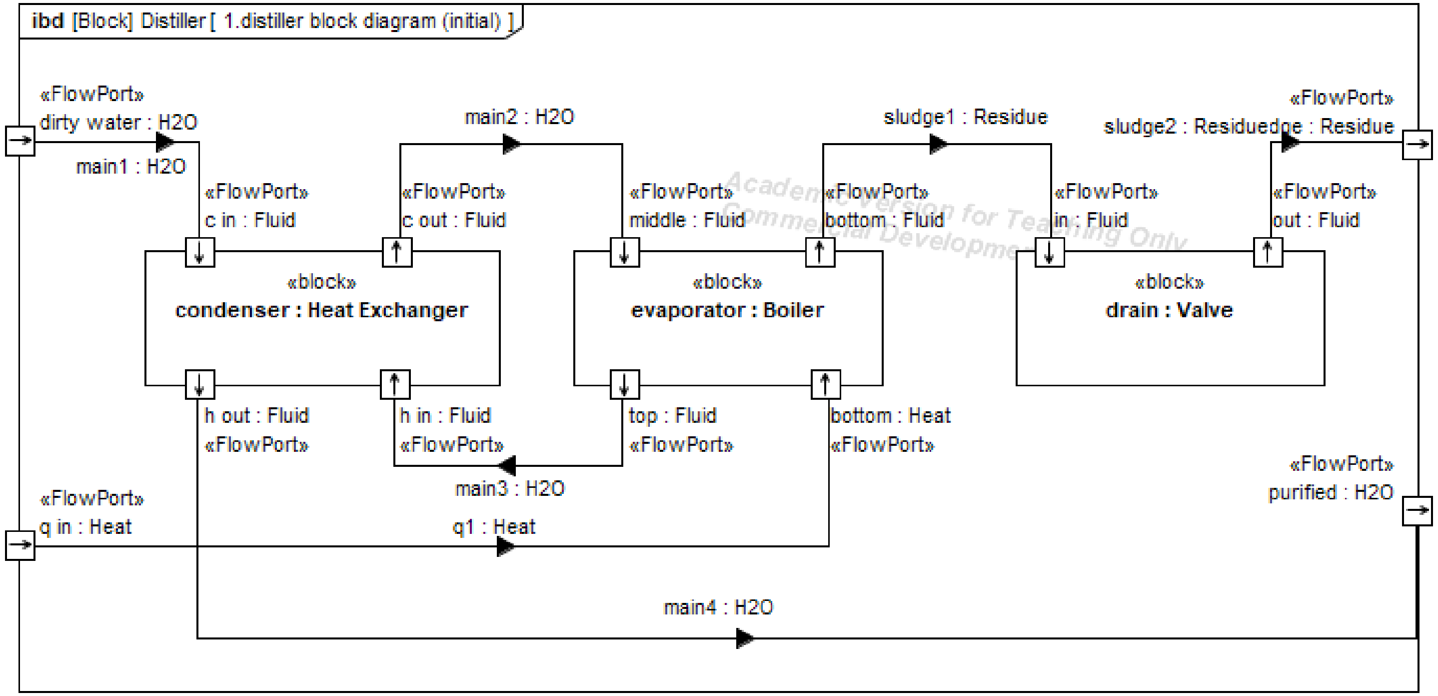
Complexity Metric:

$$C = \sum_{i=1}^{n}\alpha_i + \left(\sum_{i=1}^{n}\sum_{j=1}^{n}\beta_{ij} + \sum_{i=1}^{n}\sum_{m=1}^{q}\gamma_{im}\right)\frac{v}{n}$$

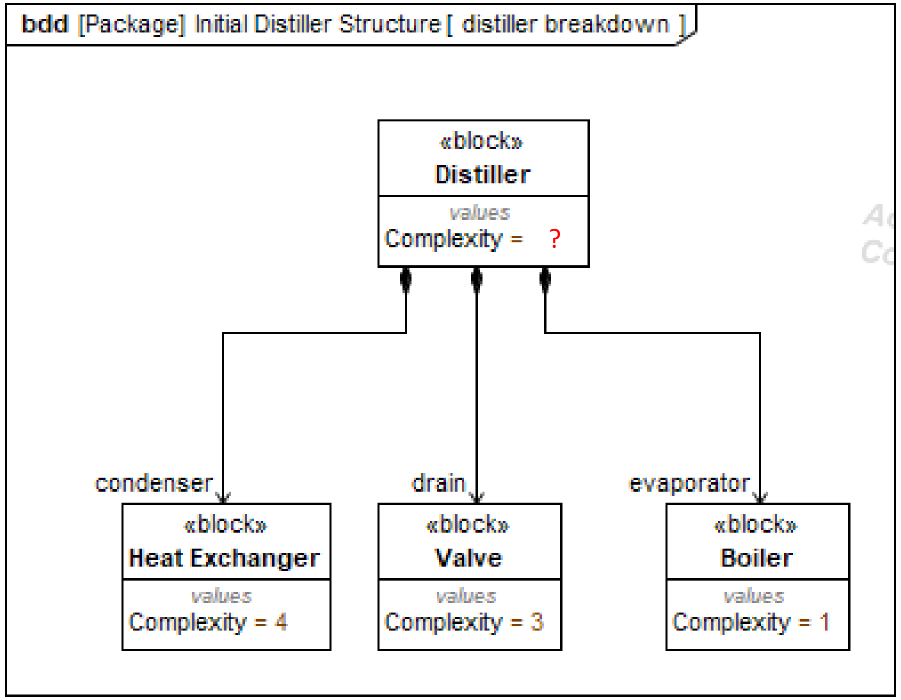
n: number of internal components
q: number of external components
α_i: Complexity of ith component
β_{ij}: Complexity of the interaction between the ith and jth components
γ_{im}: Complexity of the interaction between the ith internal component and mth external component
v: Cyclomatic complexity as adapted by Lankford for class diagrams

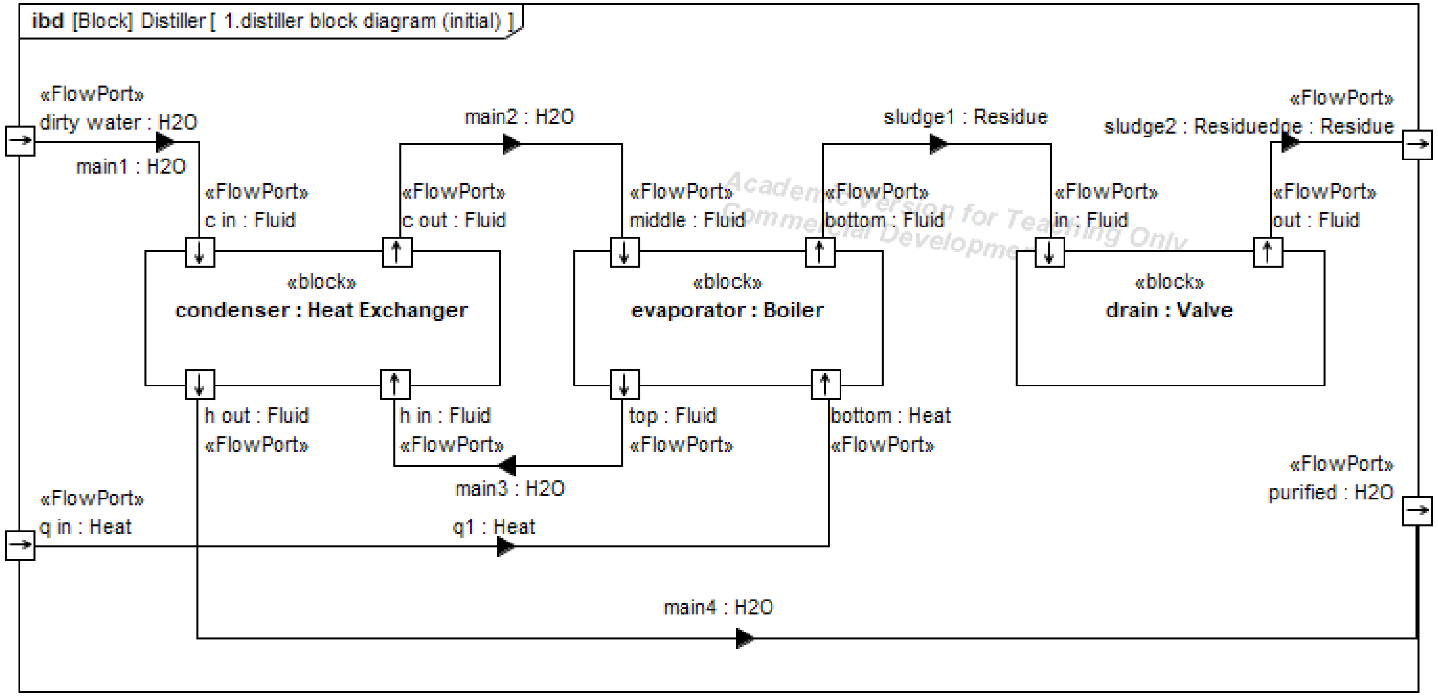
Complexity Metric - Example





Complexity Metric - Example





Interaction Type	Complexity
H20	.8
Residue	.5
Heat	1

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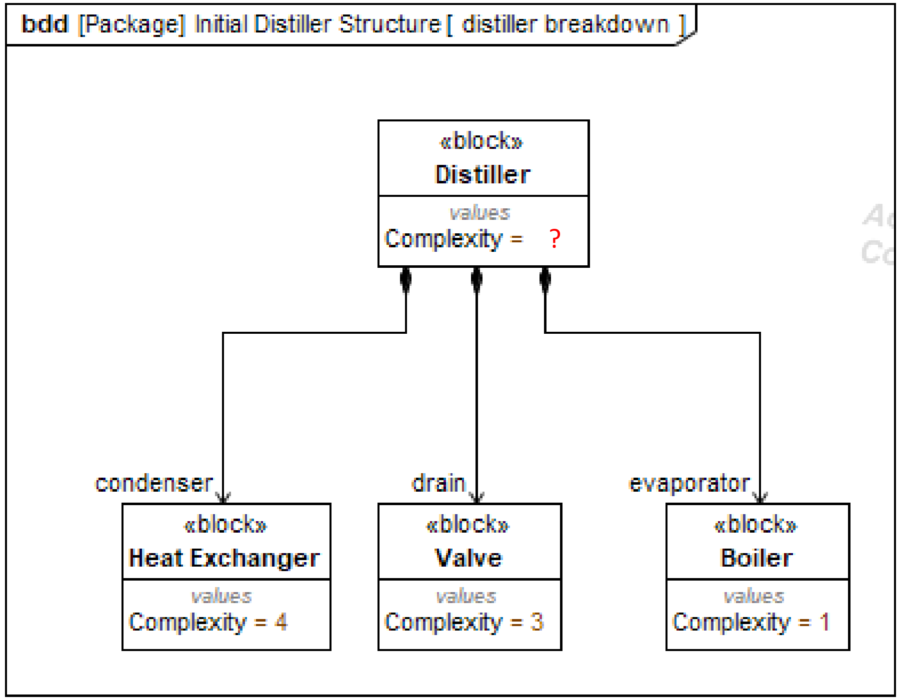
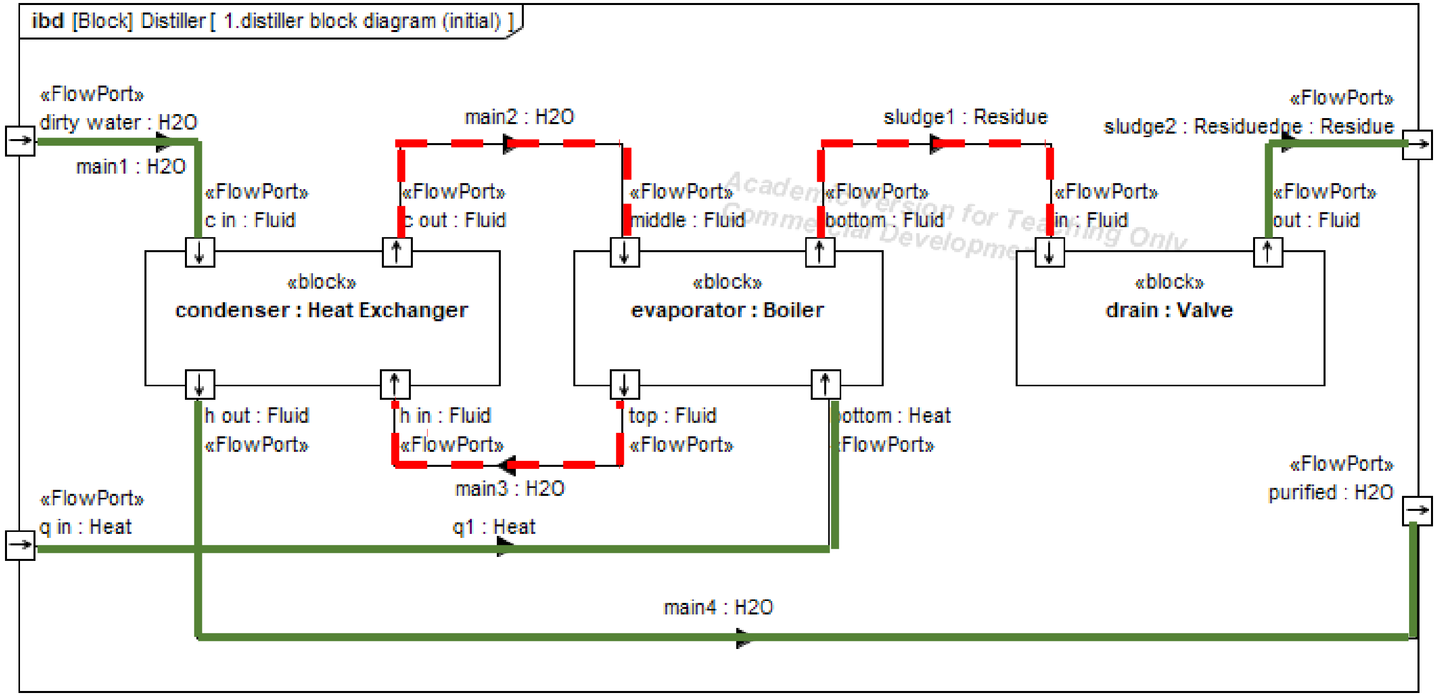
Complexity Metric - Example





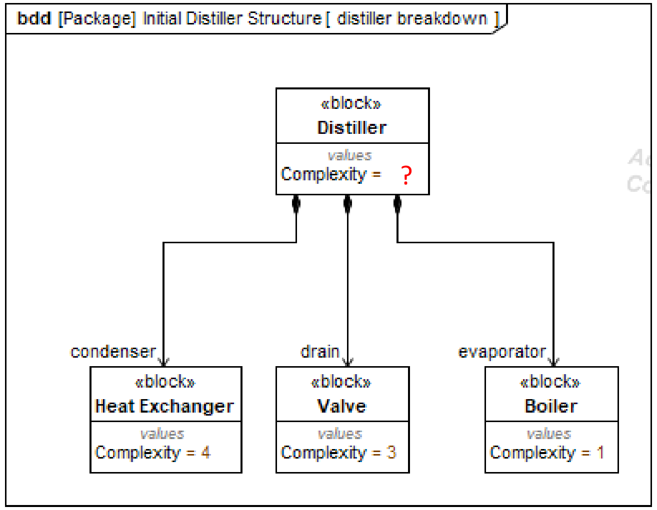
Interaction Type	Complexity	Internal (β)	External (γ)
H20	.8	2	2
Residue	.5	1	1
Heat	1	0	1

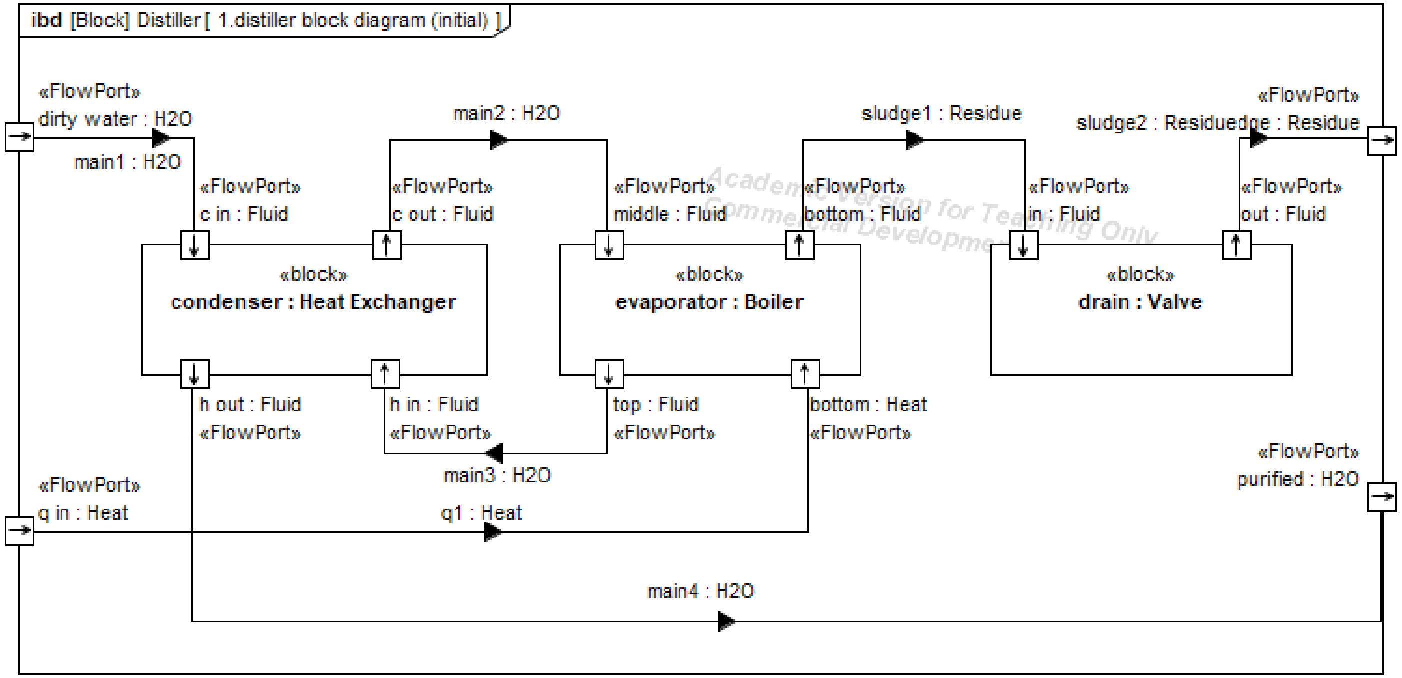
Complexity Metric - Example

Cyclomatic complexity as adapted by Lankford

$$v = e - n + 2p$$

- e = Number of relations
- n = Number of blocks
- p = Number of graph connected components





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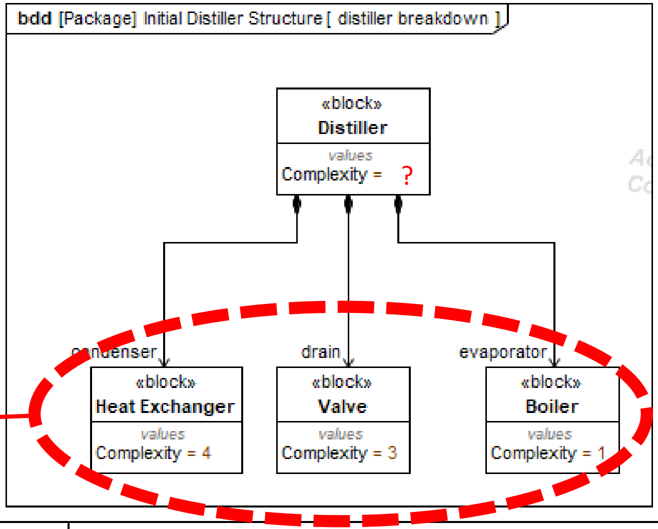
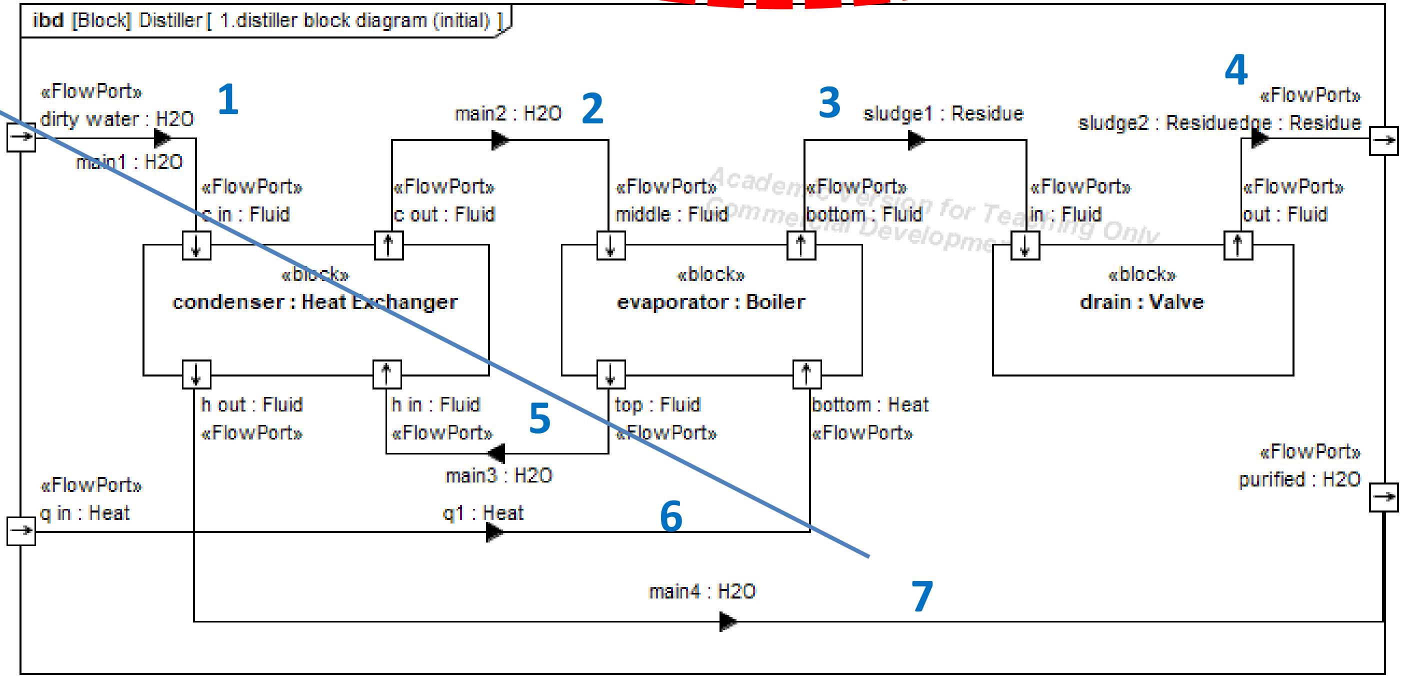
Complexity Metric - Example

Cyclomatic complexity as adapted by Lankford

$$v = e - n + 2p$$

- e = Number of relations : 7
- n = Number of components : 3
- p = Number of graph connected components : 1





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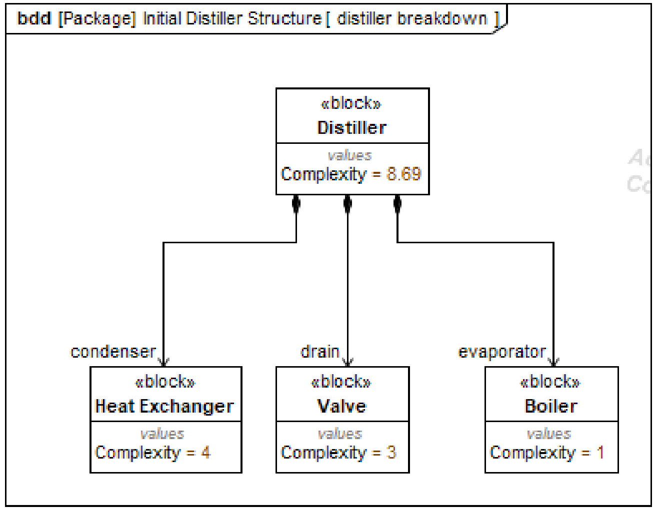
Complexity Metric - Example

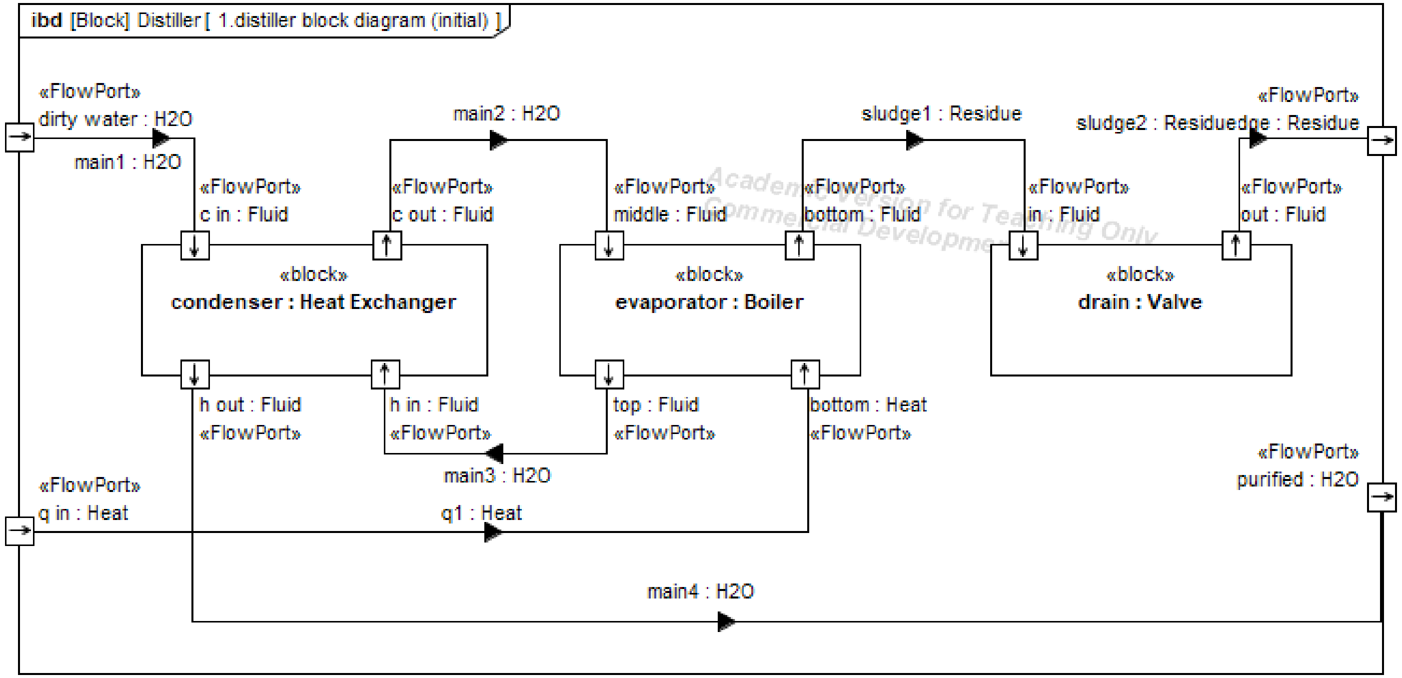
Cyclomatic complexity as adapted by Lankford

$$v = e - n + 2p$$

- e = Number of relations : 7
- n = Number of components : 3
- p = Number of graph connected components : 1

$$v = 7 - 3 + 2(1) = 6$$





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Complexity Metric - Example

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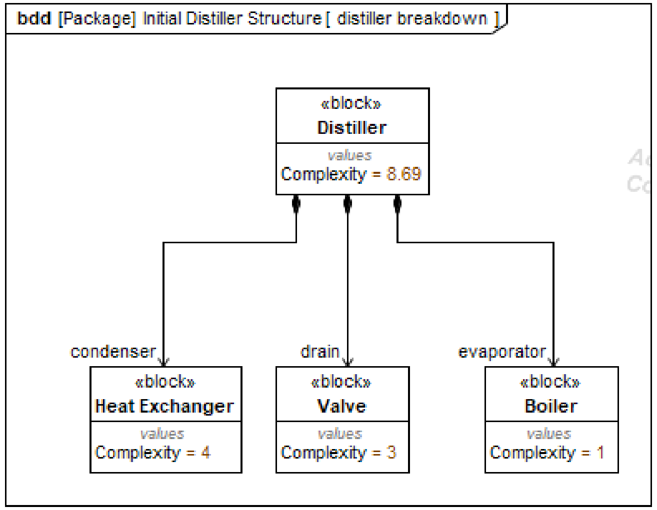
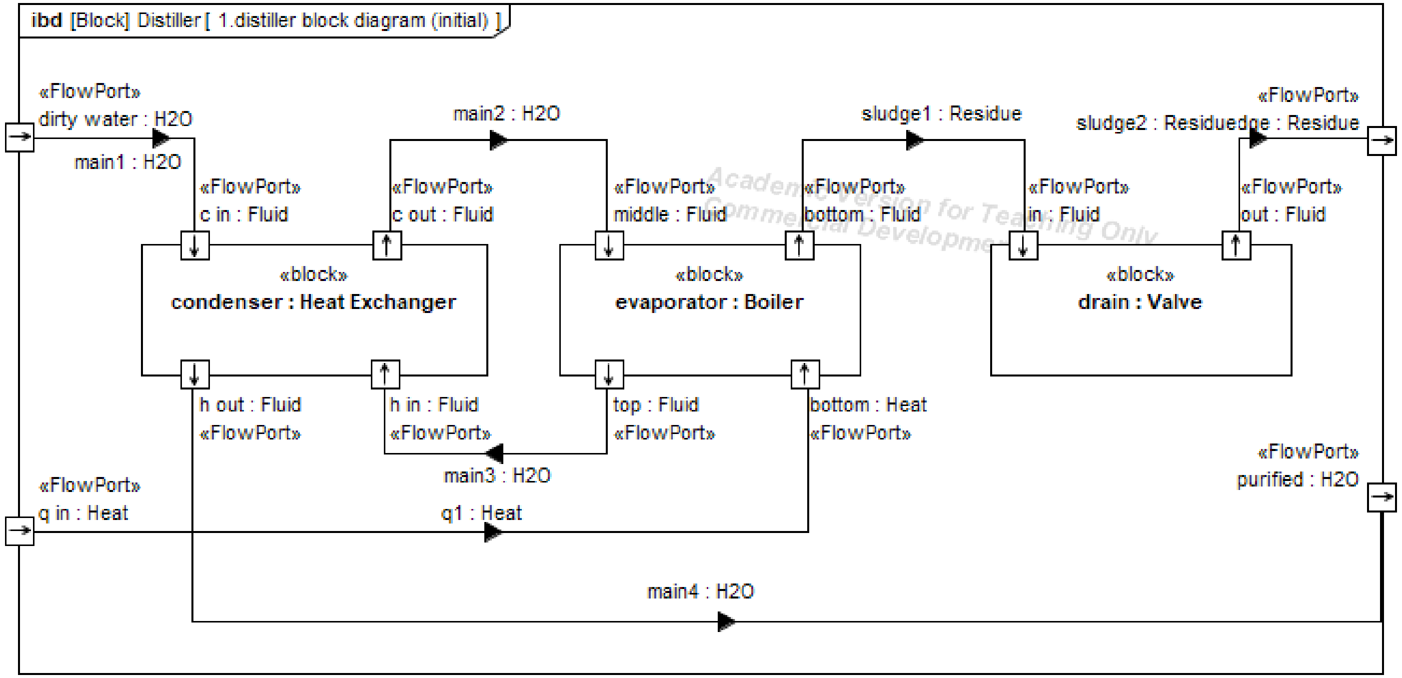
$$C = \sum_{i=1}^{n} \alpha_i + \left(\sum_{i=1}^{n} \sum_{j=1}^{n} \beta_{ij} + \sum_{i=1}^{n} \sum_{m=1}^{q} \gamma_{im} \right) \frac{v}{n}$$





Complexity Metric - Example

Cyclomatic complexity as adapted by Lankford

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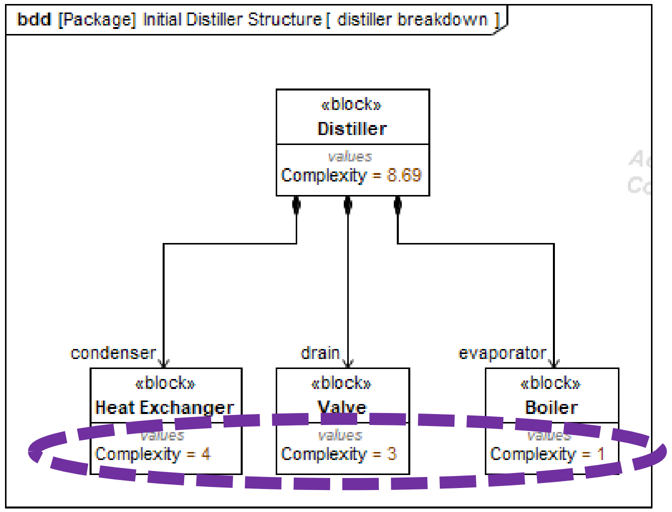
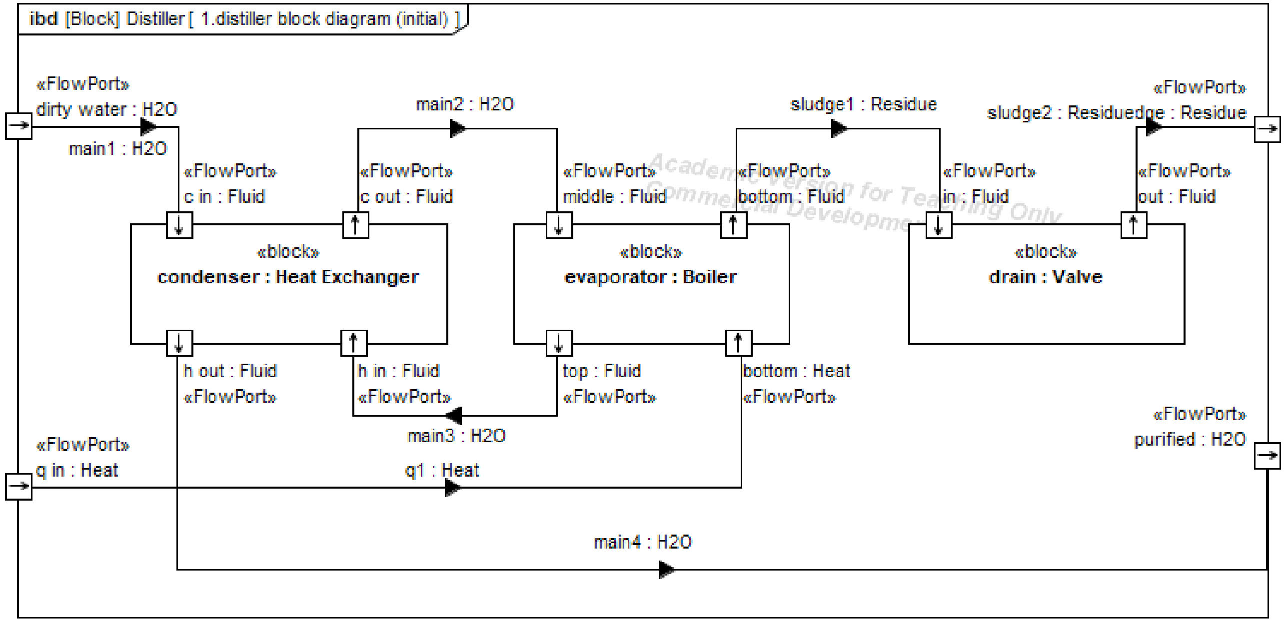
$$C = [4 + 3 + 1] + [(2 * 0.8 + 1 * 0.5) + (2 * 0.8 + 1 * 1 + 1 * 0.5)] * \frac{6}{3}$$





Interaction Type	Complexity	Internal (β)	External (γ)
H20	.8	2	2
Residue	.5	1	1
Heat	1	0	1

Complexity Metric - Example

Cyclomatic complexity as adapted by Lankford

$$v = e - n + 2p$$

- e = Number of relations : 7
- n = Number of components : 3
- p = Number of graph connected components : 1

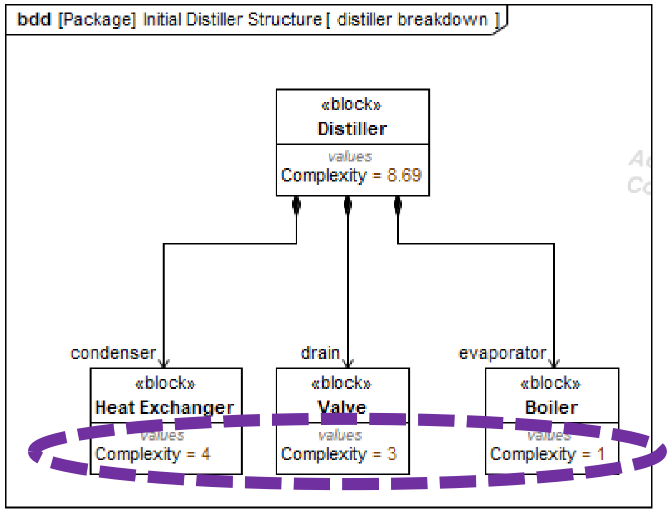
$$v = 7 - 3 + 2(1) = 6$$

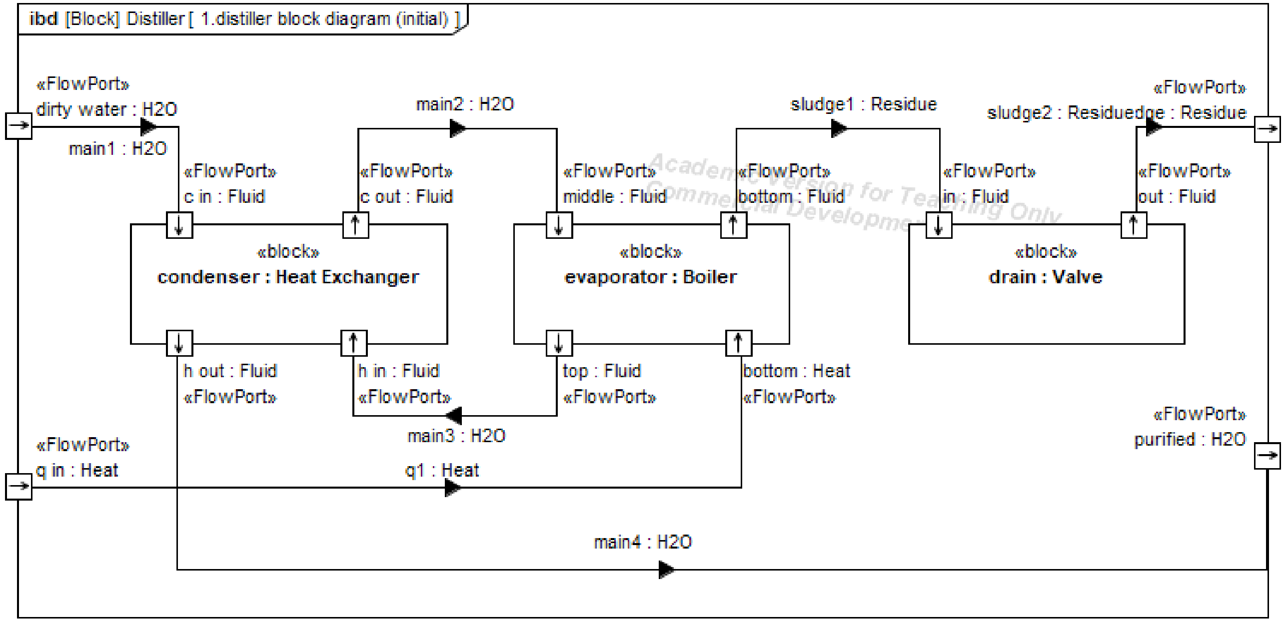
$$C = \sum_{i=1}^{n} \alpha_i + \left(\sum_{i=1}^{n}\sum_{j=1}^{n} \beta_{ij} + \sum_{i=1}^{n}\sum_{m=1}^{q} \gamma_{im}\right)\frac{v}{n}$$

$$C = [4 + 3 + 1] + [(2 * 0.8 + 1 * 0.5) + (2 * 0.8 + 1 * 1 + 1 * 0.5)] * \frac{6}{3}$$

$$C = 8 + 5.2 * \frac{6}{3}$$

$$\boldsymbol{C = 18.4}$$





Interaction Type	Complexity	Internal (β)	External (γ)
H20	.8	2	2
Residue	.5	1	1
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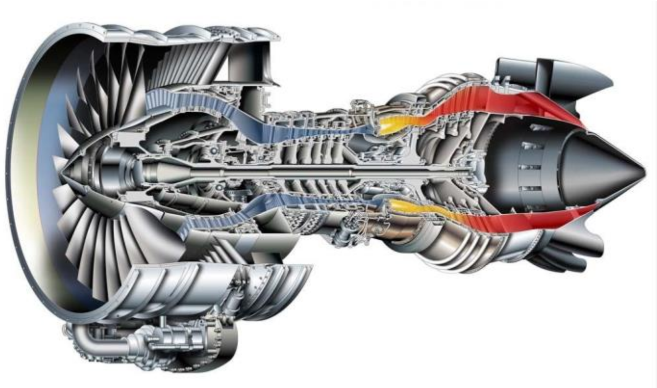
Case Study: Turbofan Engine

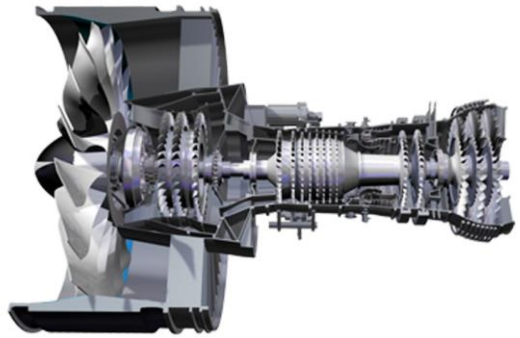
Comparison:

PW4098



Two spool high bypass ratio Turbofan

PW1524G



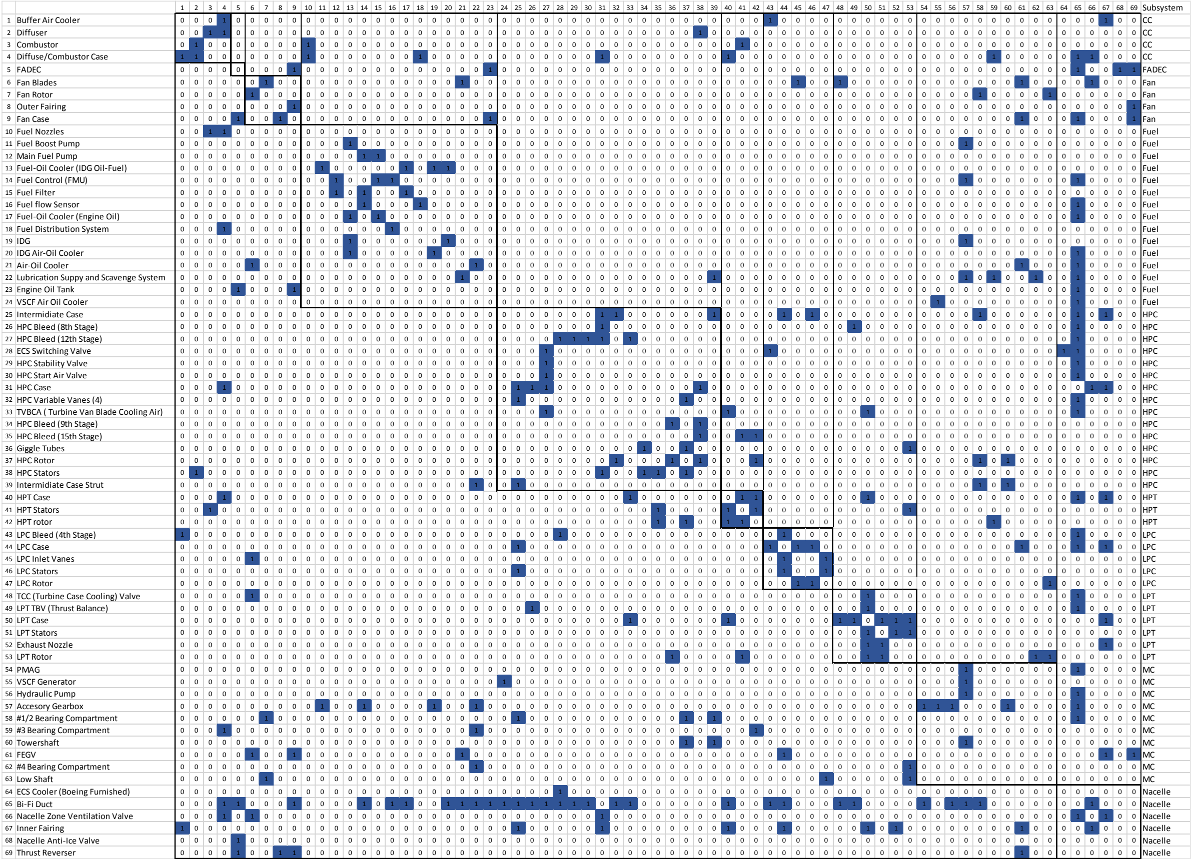
high-bypass geared turbofan

Initial assumptions:
- All component complexity equal to 1
- Interaction between components equal to 0.1
- Interactions between subsystems equal to 0.2

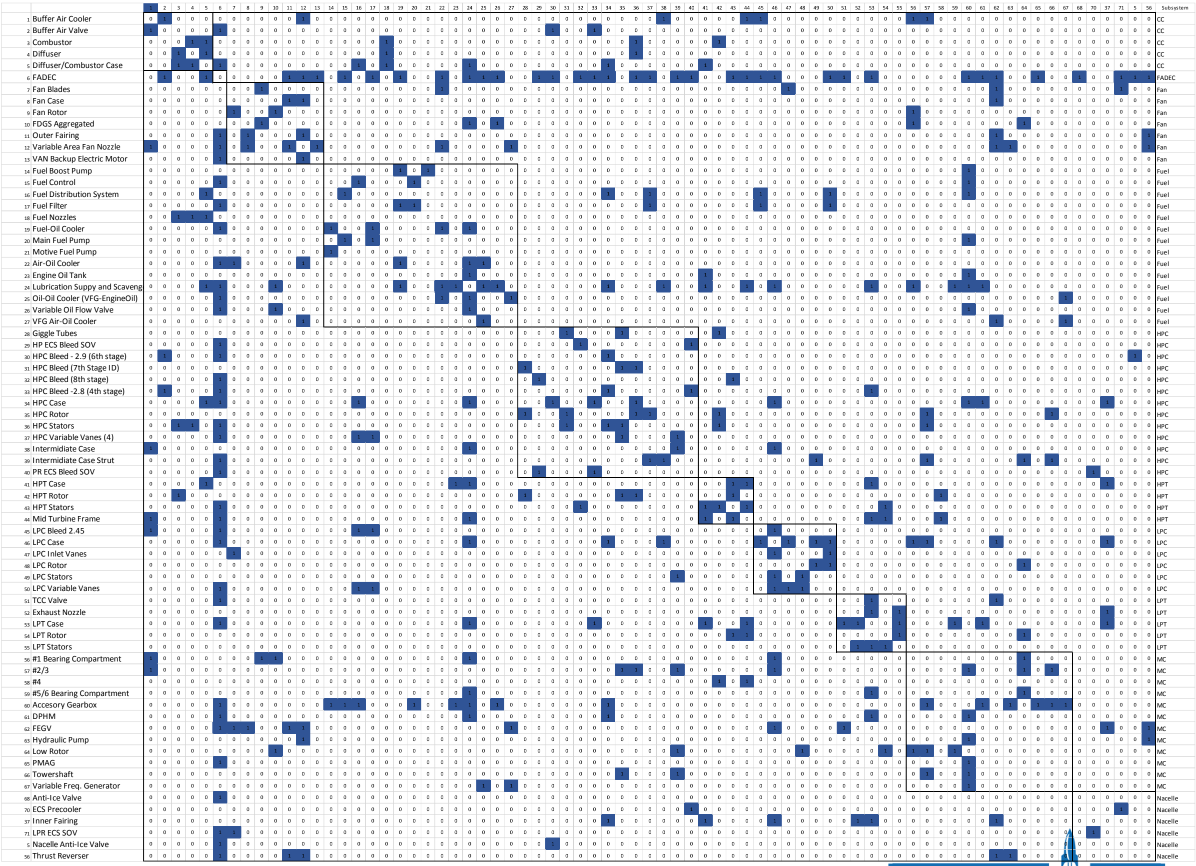
Case Study: Turbofan Engine

Comparison:

PW4098



PW1524G



Data from: @ James et al.

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Case Study: Turbofan Engine

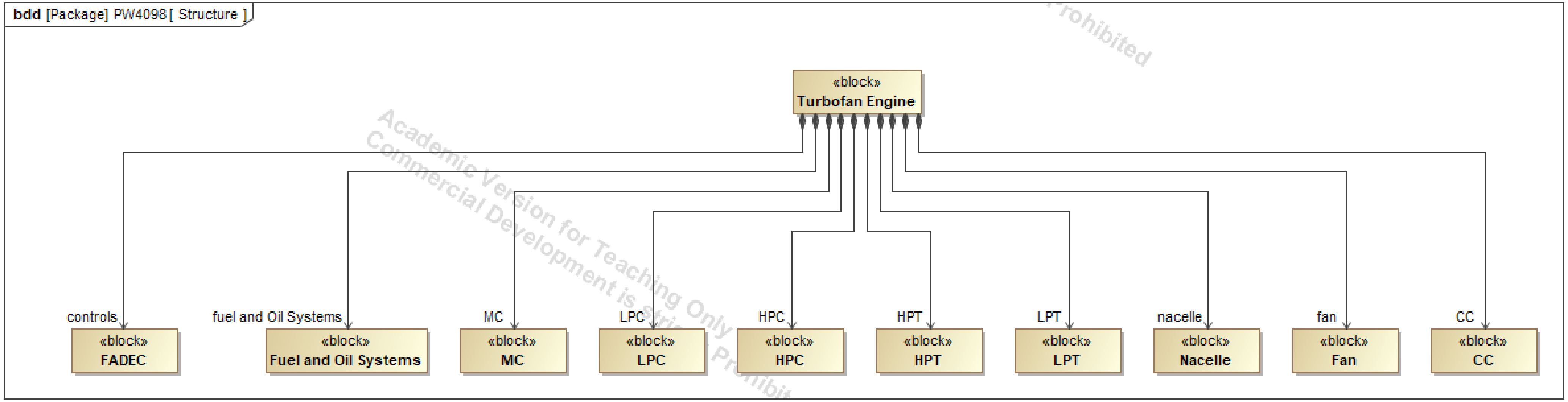
Complexity assessment analysis on 2 turbofan engines:

- PW4098 (69 Components, 268 interactions)
- PW1524G (73 Components, 373 interactions)

Data from: @ James et al.

2 SysML models were created with the same 10 subsystems:

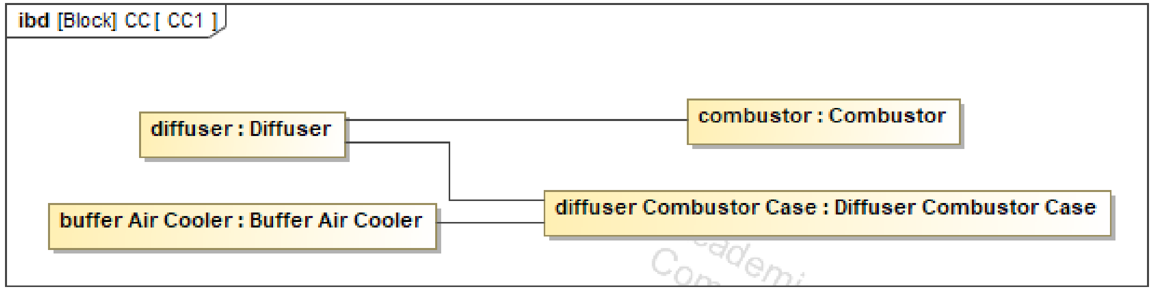
- All parts were assigned to a subsystem



Case Study: Turbofan Engine

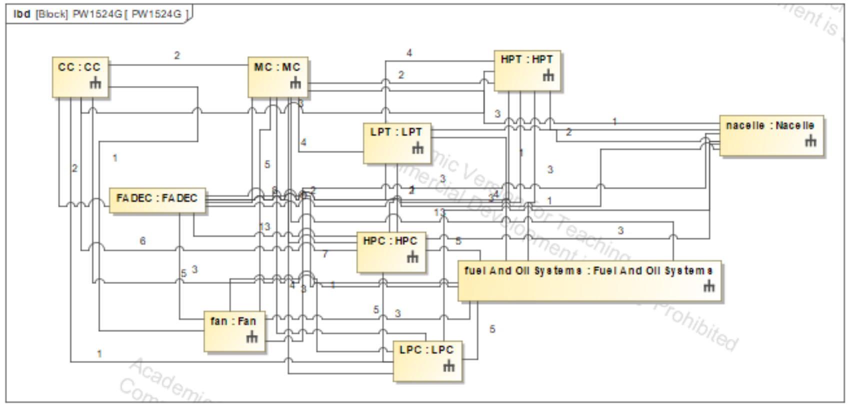
For each subsystem an internal block diagram was made:

Showing interactions between elements of the subsystem



Then an internal block diagram was made for the engine

Showing interactions between the subsystems



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Case Study: Turbofan Engine

Results the metric used in this study

- Complexity of components = 1
- Complexity of interactions between components = 0.1
- Complexity of interactions between subsystems = 0.2

	PW4098			PW1524G			% Difference		
	αi	Σβi	v/n	αi	Σβi	v/n	αi	Σβi	v/n
Combustion Chamber	4.08	1.20	0.25	5.24	2.00	0.60	25.01	50.00	82.35
FADEC	1.00	0.50	1.00	1.00	4.00	1.00	0.00	155.56	0.00
Fan	4.10	1.30	0.50	7.43	2.10	0.71	57.74	47.06	35.29
Fuel & Oil Systems	15.40	2.30	0.33	14.17	4.40	0.14	8.31	62.69	80.00
High Pressure Compressor	15.32	3.00	0.20	13.09	4.30	0.08	15.68	35.62	88.89
High Pressure Turbine	3.20	1.10	0.67	4.20	1.90	0.50	27.03	53.33	28.57
Low Pressure Compressor	5.20	1.00	0.40	6.35	1.80	0.50	19.91	57.14	22.22
Low Pressure Turbine	6.35	1.20	0.50	5.20	1.40	0.40	19.91	15.38	22.22
Mechanical Components	10.24	2.90	0.60	12.33	4.90	0.33	18.55	51.28	57.14
Nacelle	6.13	4.50	0.67	6.05	1.60	0.50	1.37	95.08	28.57
Sum of components	71.02	19.00		75.07	28.4		5.54	39.66	
v/n (Subcomponents)	**8.70**			**13.40**			**42.53**		
Engine	**236.32**			**455.63**			**63.39**		

Results using Sinha and Suh's metric

- Complexity of components = 1
- Complexity of interactions between components = 0.1

	PW4098	PW1524G	% Difference
Sum of components	69.00	73.00	5.63
Σβij	26.80	37.30	32.76
E(A)	95.98	117.81	20.42
E(A)/n	1.62	1.79	10.24
Engine	**104.24**	**133.20**	**24.39**

Case Study: Turbofan Engine

Results the metric used in this study

- Complexity of components = 1
- Complexity of interactions between components = 0.2
- Complexity of interactions between subsystems = 0.2

	PW4098			PW1524G			% Difference		
	αi	Σβi	v/n	αi	Σβi	v/n	αi	Σβi	v/n
Combustion Chamber	4.15	1.20	0.25	5.48	2.00	0.60	27.62	50.00	82.35
FADEC	1.00	0.50	1.00	1.00	4.00	1.00	0.00	155.56	0.00
Fan	4.20	1.30	0.50	7.86	2.10	0.71	60.66	47.06	35.29
Fuel & Oil Systems	15.80	2.30	0.33	14.34	4.40	0.14	9.67	62.69	80.00
High Pressure Compressor	15.64	3.00	0.20	13.18	4.30	0.08	17.04	35.62	88.89
High Pressure Turbine	3.40	1.10	0.67	4.40	1.90	0.50	25.64	53.33	28.57
Low Pressure Compressor	5.40	1.00	0.40	6.70	1.80	0.50	21.49	57.14	22.22
Low Pressure Turbine	6.70	1.20	0.50	5.40	1.40	0.40	21.49	15.38	22.22
Mechanical Components	10.48	2.90	0.60	12.67	4.90	0.33	18.89	51.28	57.14
Nacelle	6.27	4.50	0.67	6.10	1.60	0.50	2.70	95.08	28.57
Sum of components	73.04	19.00		77.13	28.4		5.45	39.66	
v/n (Subcomponents)		**8.70**			**13.40**			**42.53**	
Engine		**238.34**			**457.69**			**63.03**	

Results using Sinha and Suh's metric

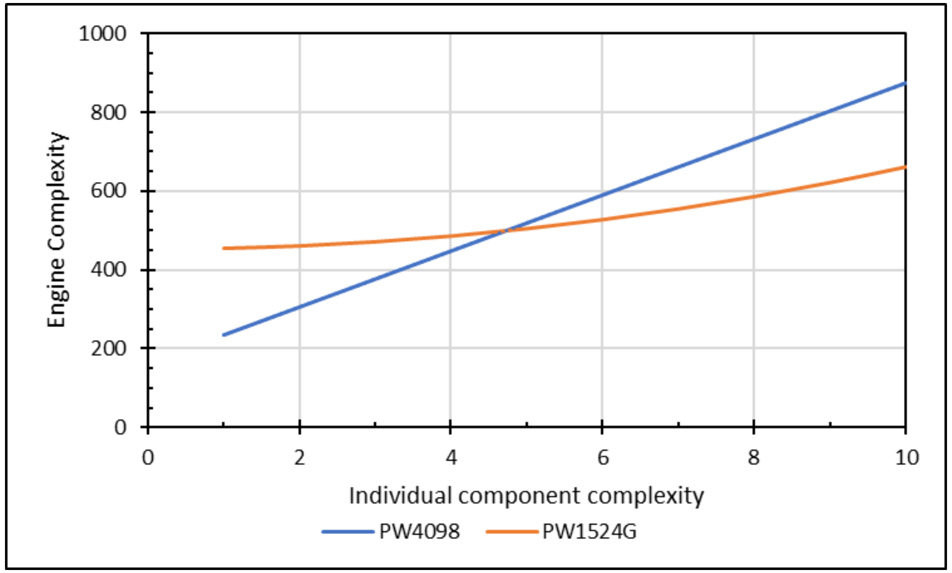
- Complexity of components = 1
- Complexity of interactions between components = 0.2

	PW4098	PW1524G	% Difference
Sum of components	69.00	73.00	5.63
Σβij	53.60	74.60	32.76
E(A)	95.98	117.81	20.42
E(A)/n	1.62	1.79	10.24
Engine	**139.47**	**193.39**	**32.40**

Case Study: Turbofan Engine

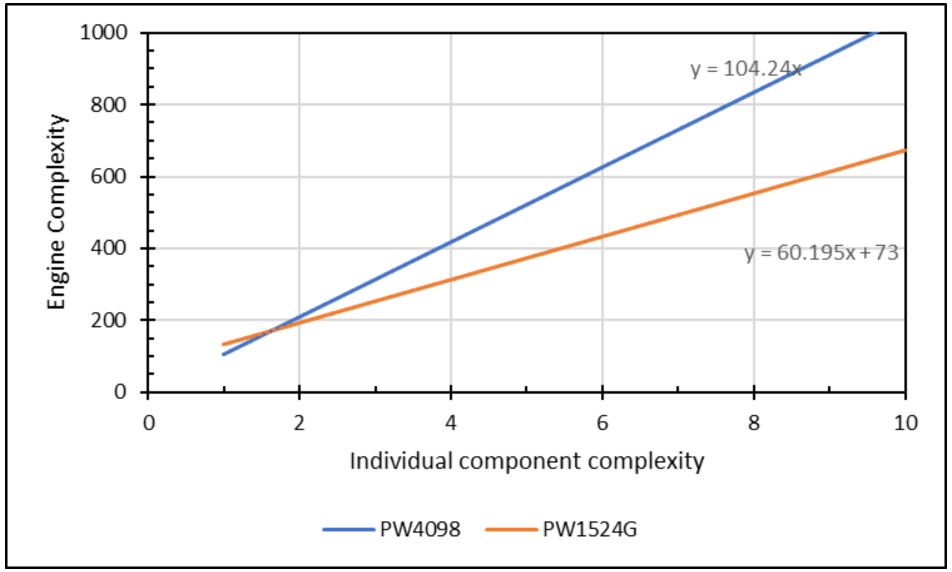
Results the metric used in this study

- Complexity of components varied from 1 to 10
- Complexity of interactions between components = 0.1
- Complexity of interactions between subsystems = 0.2



Results using Sinha and Suh’s metric

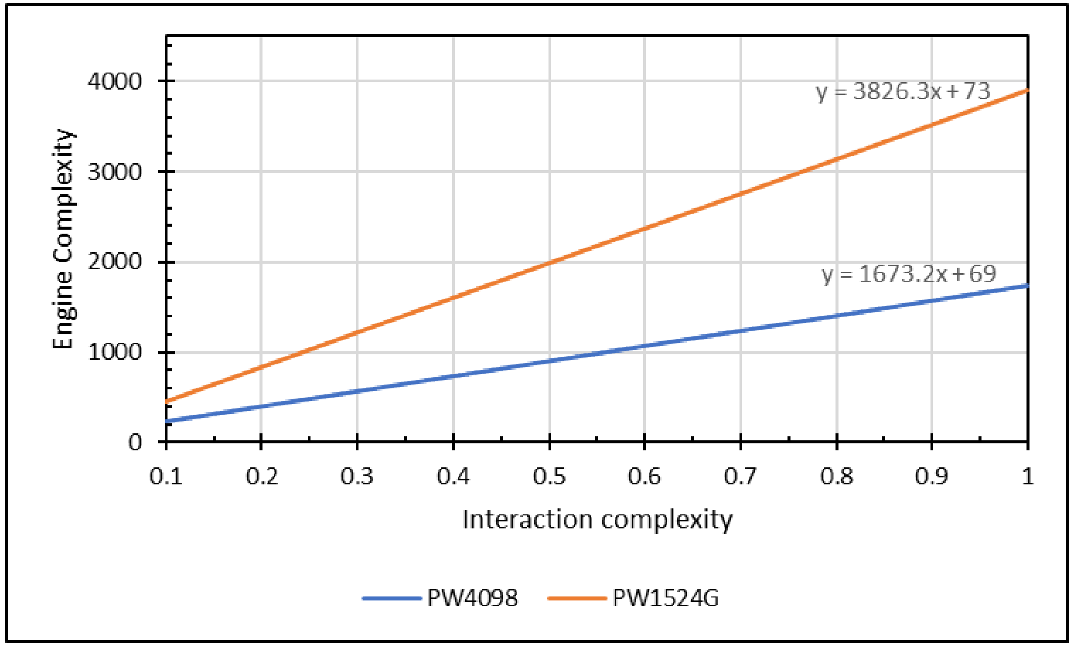
- Complexity of components varied from 1 to 10
- Complexity of interactions = 0.1



Case Study: Turbofan Engine

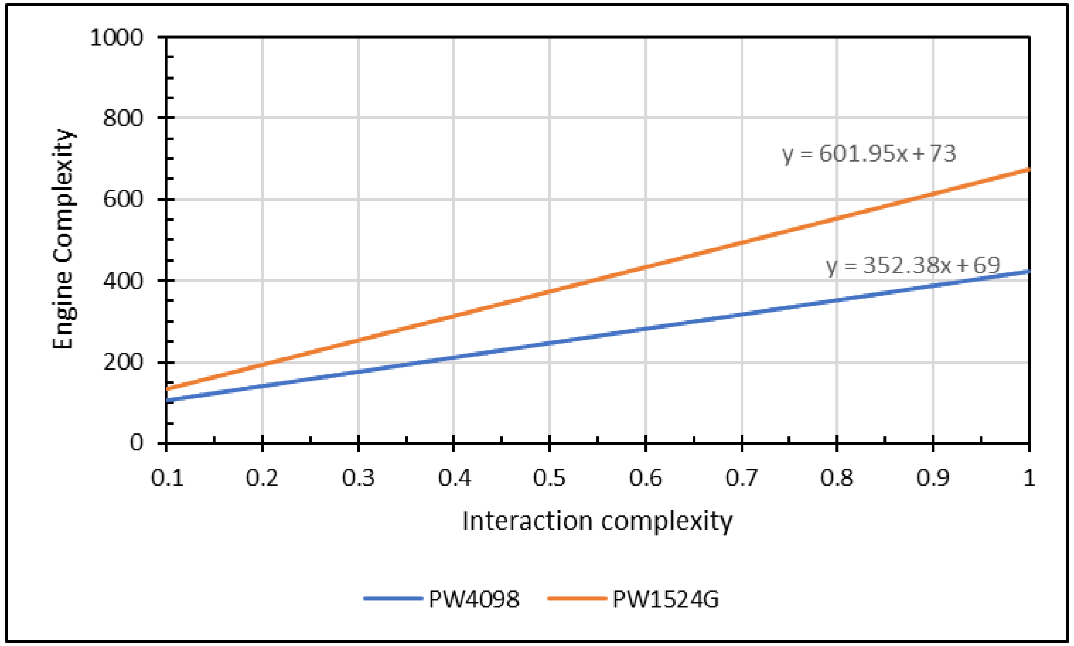
Results the metric used in this study

- Complexity of components = 1
- Complexity of all interactions between components varied from 0.1 to 1



Results using Sinha and Suh's metric

- Complexity of components = 1
- Complexity of interactions between components varied from 0.1 to 1



Conclusions

A complexity metric has been developed:

- Calculation of complexity based on a system modelled using SysML
- Shows the same trends that previous work in complexity estimation using DSM
- Provides insight has the impact of increasing interaction, and component complexity

Current State of the Research:

- Metric is being applied to other engineered systems

Future Work:

- Create a function or methodology to estimate complexity based on the resources spent: C = F(time, cost, Number of Engineer, Risk…)
- Compare complexity estimation to actual systems data

Questions?

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