International Council on Systems Engineering
A better world through a systems approach

Integrating PLE to Enhance MBSE Education in Emerging Engineering Countries:

The Singapore Institute of Technology (SIT) Example

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Presenter

Marco Forlingieri

Senior Director for Product Line Engineering (PLE) at **PTC,** leads the biggest PLE expert´s pool in the world. He has **several years of experience** in the field of **MBSE** and **PLE** mainly within **aerospace, defense, automotive** and **railway industries** in **Europe**, **China** and **North America**. **He chairs the INCOSE PLE Working Group** and is the leading author of the **book MBPLE: The Feature-Based Path to Product Lines Success, published by Wiley.** Former **Faculty Associate** at Singapore Institute of Technology (**SIT**).

Can MBSE be taught and understood anywhere?

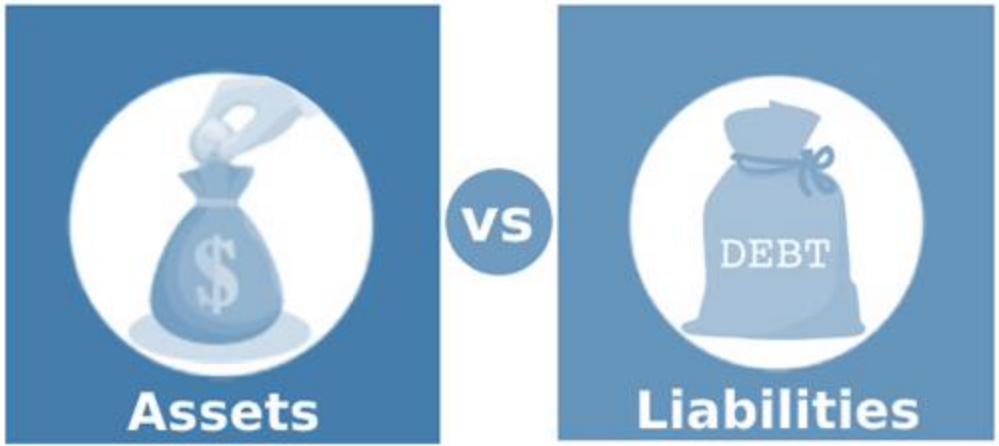
SINGAPORE INSTITUTE OF TECHNOLOGY

Poor Dad Engineering vs Rich Dad Engineering

REUSABLE ASSETS

- Items of **value**
- **Generate revenues** for the business
- Provide l**ong-term benefits**

Reusable Models



NON REUSABLE LEGACY

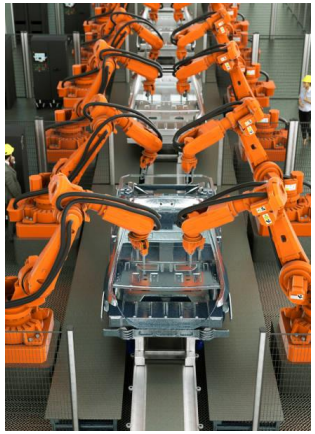
- Items of **no future value**
- **Generate cost** for the business
- Provide **long-term technical debts**

One-shot Models

> *An asset puts money in my pocket. A liability takes money out of my pocket.*
>
> *Robert Kiyosaki*

The Context: Teaching MBSE in Singapore (and ASEAN)

Manufacturing & Services Focus



Focus more on **manufacturing** and **services** often find it **challenging** to justify both the learning and **application of MBSE** and the associated investment.

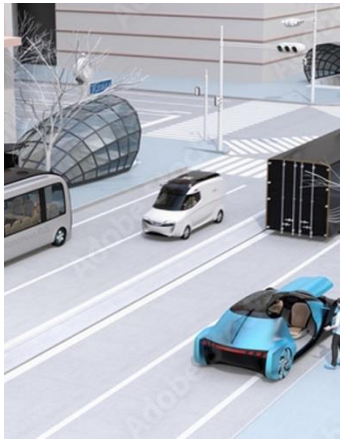
Teaching MBSE in ASEAN Universities

Singapore and the **Southeast Asia region** exemplify this challenge, which extends **not only** to **industrial adoption** but also to **academic institutions** where MBSE education is limited.

No MBSE Mandate and Large Adoptions

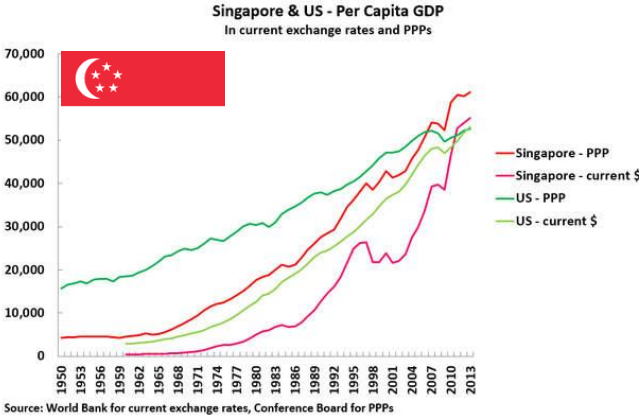
Singapore Government spends large **investment** in the **defense sector**, but **no existing large-scale MBSE** implementation in the country. The investment mainly consists of the **acquisition** of **defense systems from other countries.**

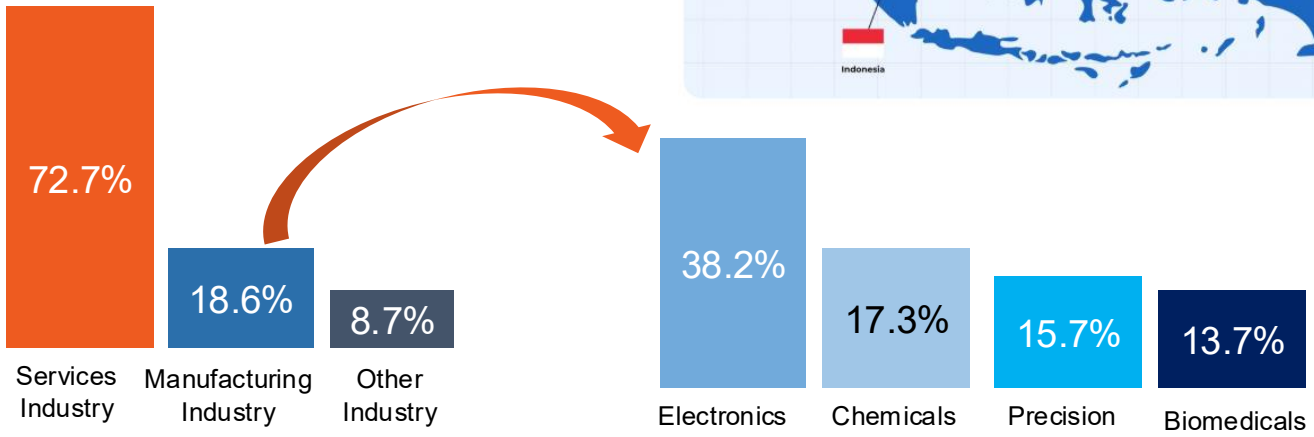
Very few Complex & Safety Critical Systems



Teaching and **learning** **MBSE** in countries that do **not typically develop safety-critical or highly complex systems**, such as aerospace, automotive, transportation,

Singapore: What an “Emerging Engineering Country” Looks Like





Our Assumptions and Goal: Combine MBSE with Product Line Engineering (PLE)

Models Reuse as key benefits

A key **advantage** of **MBSE** is **model reuse**. Avoiding unnecessary repetition characterizes efficiency, and **the benefits of reusing models—like other engineering artifacts—are almost intuitive**, resulting in cost savings, improved quality, and other advantages.

Practical vs. Abstract

Concepts central to **Product Line Engineering** (PLE), such as **commonality** and **variability**, are more **tangible and familiar,** making them **easier to grasp than more abstract MBSE concepts** like architectural layers, abstraction, or system simulation.

PLE can boost MBSE

If **PLE** is Introduced **in combination with the teaching of MBSE**, it can **facilitate the understanding** of the discipline and its benefits.

Our Goal

- **This paper** aims to **demonstrate that integrating MBSE education with** the principles and application of **PLE enhances learners' understanding of MBSE**. It reflects on a two-year experience of teaching MBSE to **2 cohorts of Mechatronics Systems students**, with class sizes of 56 and 51, at the **Singapore Institute of Technology**.

Singapore Institute of Technology: MBSE Course

Year 2022-2023: 56 Students

Year 2023-2024: 56 Students

4-Year Undergraduate Program

Mechatronics Systems Program

SINGAPORE INSTITUTE OF TECHNOLOGY

30H | Lectures

- Quiz from previous class
- Facts about MBSE
- Interactive Lecture
- Break (15 -10 min)
- Open Discussion & Q&A

25h | Tutorials with Lab

- Recap of previous tutorial
- Modelling Theory
- Modelling Practice
- Break (15 -10 min)
- Open Discussion & Q&A

25h | Self-study/ Independent Study

- Read study materials
- Practice modelling

35H | Project Group Work

- Prepare presentation assignments
- Model project assignment

9H | Guest Lectures*

- External participation of MBSE expert
- Industrial case study or Deep-dive into an MBSE topic

AIRBUS

IVECO GROUP

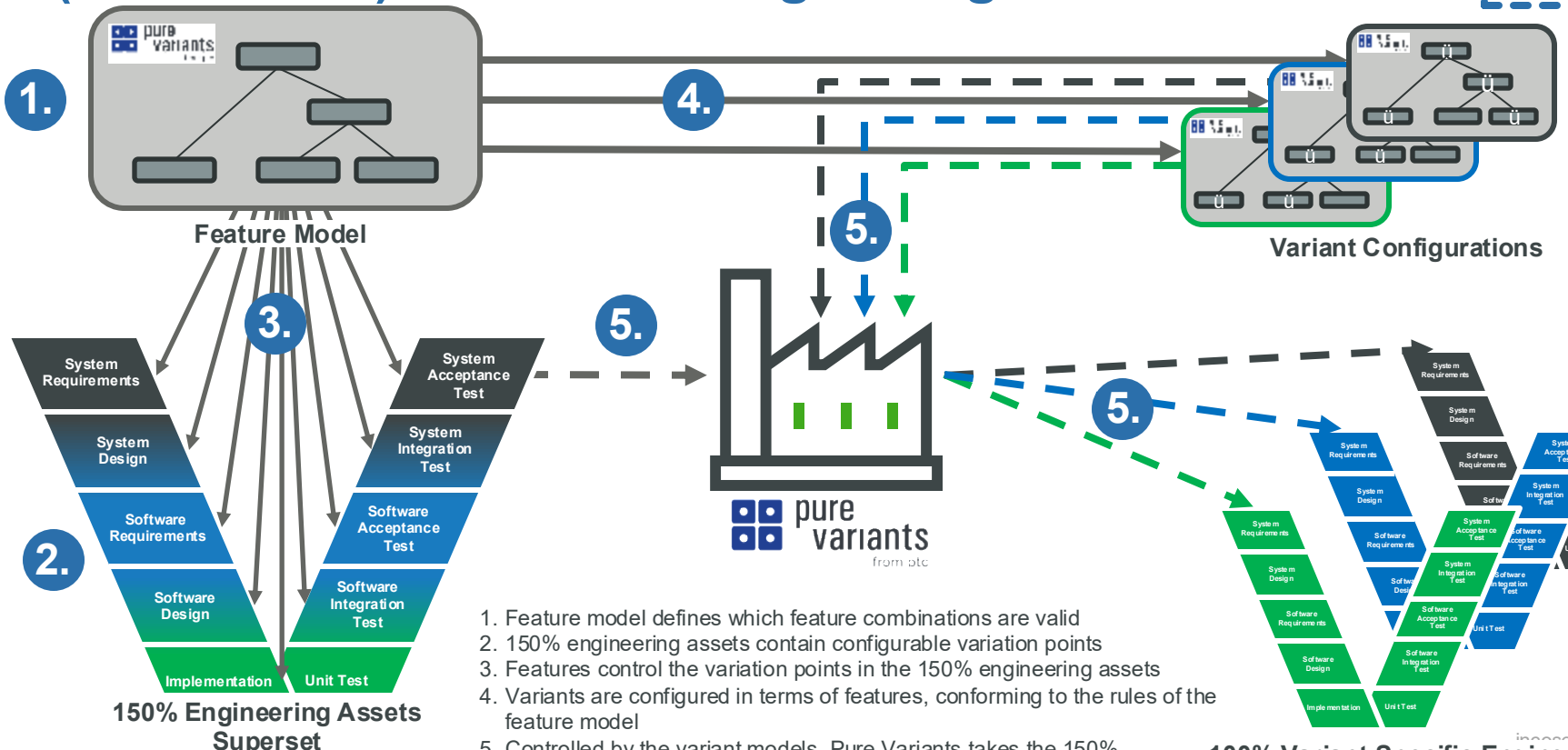
Continental

MBSE Course Program after Introducing PLE

Course Structure	Details	Introduced only in year 2024- 2025	Teaching Hours
Part I	- From SE to MBSE - MBSE Theory - Introduction to SysML	No	12 hours
Part II	- Requirements Analysis - Operational Analysis - Functional Analysis - Logical Analysis - Application of the 4 layers	No	14 hours
Part III	- PLE Theory - Variant Modeling with SysML. - Application of the MBPLE approach to the 4 layers, extending the legacy models into product line system models.	Yes	19 hours
Additional Contents	- Advanced topics and industrial cases with guest lectures, including SysML v2 and AI4MBSE	No	15 hours

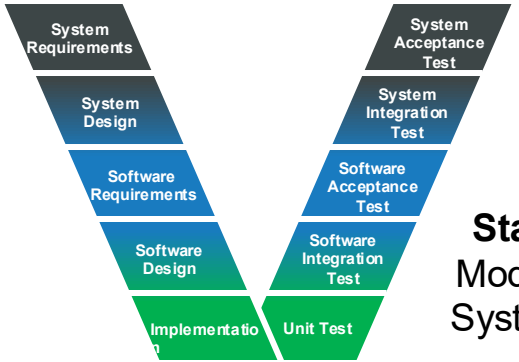
(Model-Based) Product-Line Engineering

ISO 26580

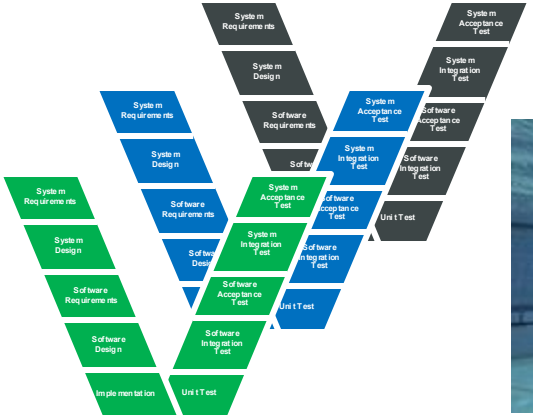


1. Feature model defines which feature combinations are valid
2. 150% engineering assets contain configurable variation points
3. Features control the variation points in the 150% engineering assets
4. Variants are configured in terms of features, conforming to the rules of the feature model
5. Controlled by the variant models, Pure Variants takes the 150% engineering assets as input to produce the 100% engineering assets for every variant.

Introducing PLE to MBSE in the Course - Theory

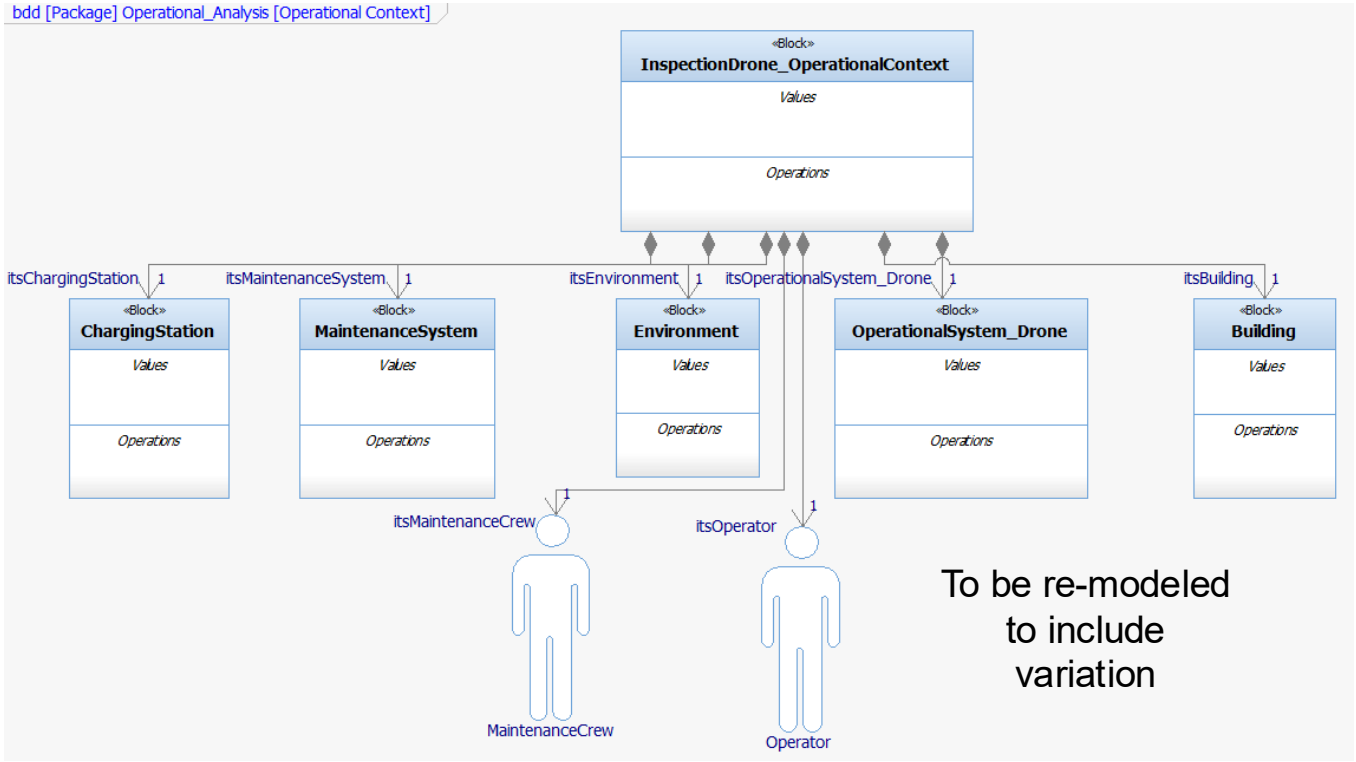


Starting Point:
Modeling a single System of Interest



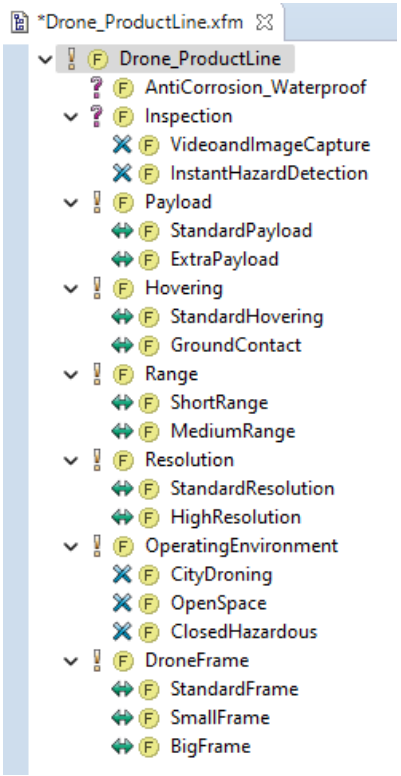
Next:
Model 3 possible variants of the System

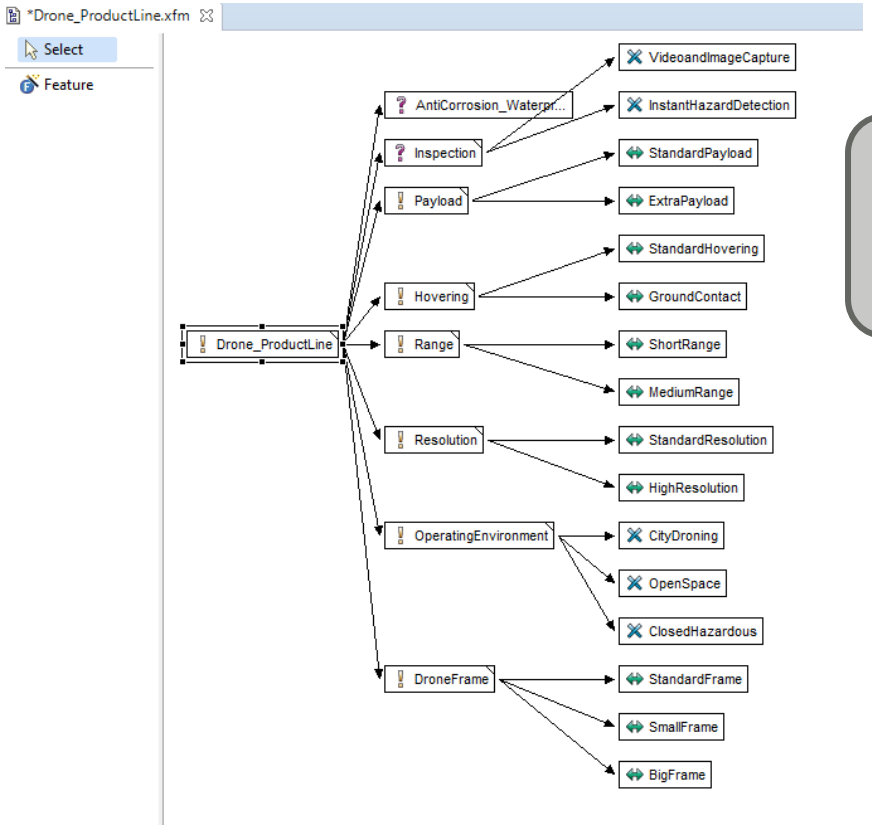
Introducing PLE to MBSE in the Course - Practice

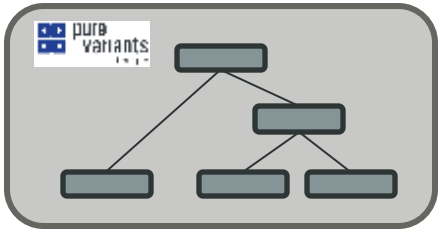


Starting Point:
Modeling a single System of Interest

Introducing PLE to MBSE in the Course - Practice







Feature Model

Model the Features as first step to extend the MBSE Model

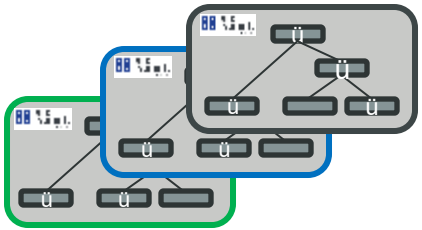
Introducing PLE to MBSE in the Course - Practice

Product Line Scoping – Variability Drivers	Building Inspection	Pipeline Inspection	Delivery
Inspection	X	X	
Image capture	X	X	X
Video capture	X	X	
Extended Range			X
Payload Additional Capacity			X
Extended Resolution		X	
Anti-corrosion and Waterproof material		X	
Instant Inspection Hazard Detection		X	
Limited Hovering		X	

Focus on the drivers of variability and use them to derive the Variant Configurations

Drone_ProductLine.xfm | *Drone_Configurations

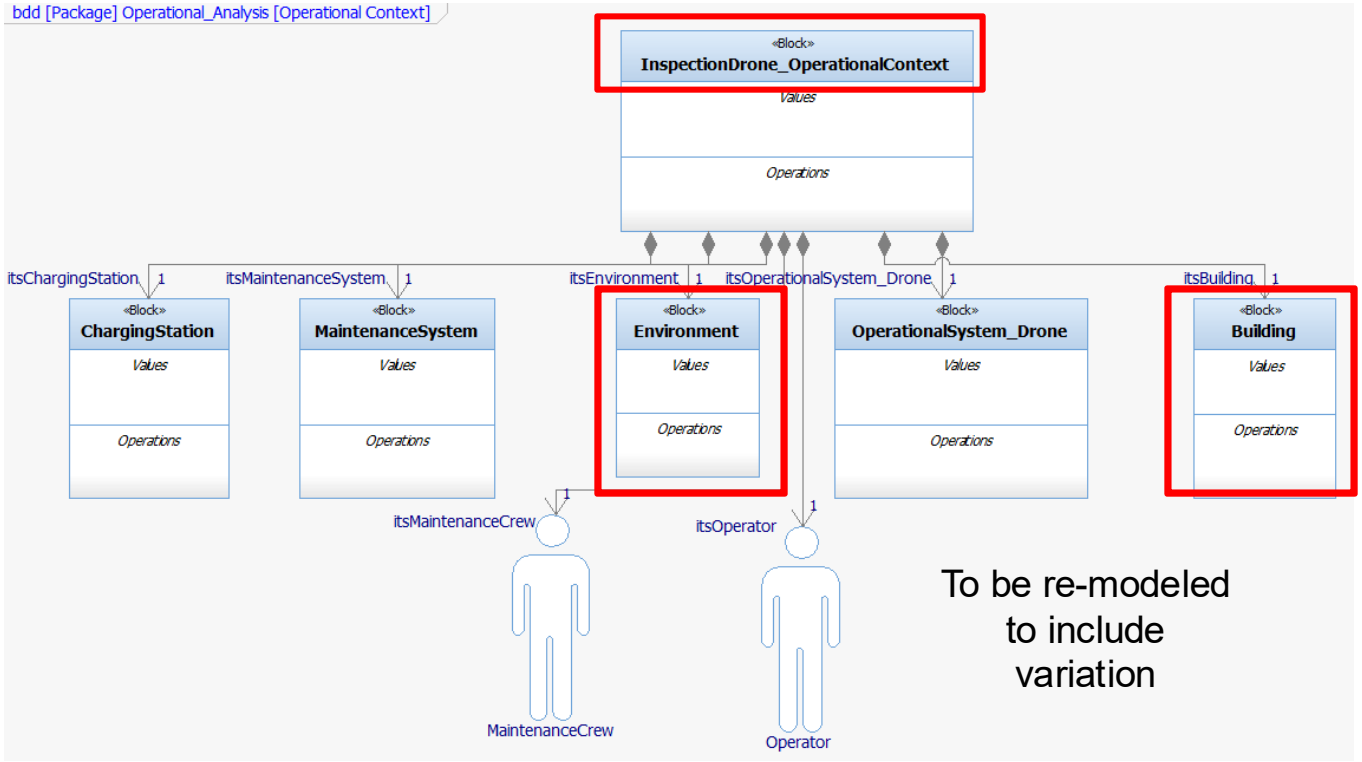
Model Elements	Level	DeliveryDrone	InspectionDrone_Baseline	InspectionDrone_Pipelines
AntiCorrosion_Waterproof	1	☐	☐	☑
Inspection	2	✓	☑	☑
VideoandImageCapture	2.1	☑	☐	☐
InstantHazardDetection	2.2	☒	☐	☑
Payload	3	✓	✓	✓
StandardPayload	3.1	☒	☑	☑
ExtraPayload	3.2	☑	☒	☒
Hovering	4	✓	✓	✓
StandardHovering	4.1	☑	☑	☒
GroundContact	4.2	☒	☒	☑
Range	5	✓	✓	✓
ShortRange	5.1	☒	☑	☒
MediumRange	5.2	☑	☒	☑
Resolution	6	✓	✓	✓
StandardResolution	6.1	☑	☒	☒
HighResolution	6.2	☒	☑	✓
OperatingEnvironment	7	✓	✓	✓
CityDroning	7.1	☑	☑	☐
OpenSpace	7.2	☑	☑	☑
ClosedHazardous	7.3	☐	☐	☑
DroneFrame	8	✓	✓	✓
StandardFrame	8.1	☒	☑	☒
SmallFrame	8.2	☒	☒	☑
BigFrame	8.3	☑	☒	☒



Variant Configurations

Model the Variant Configurations to understand what is included in each variant

Introducing PLE to MBSE in the Course - Practice

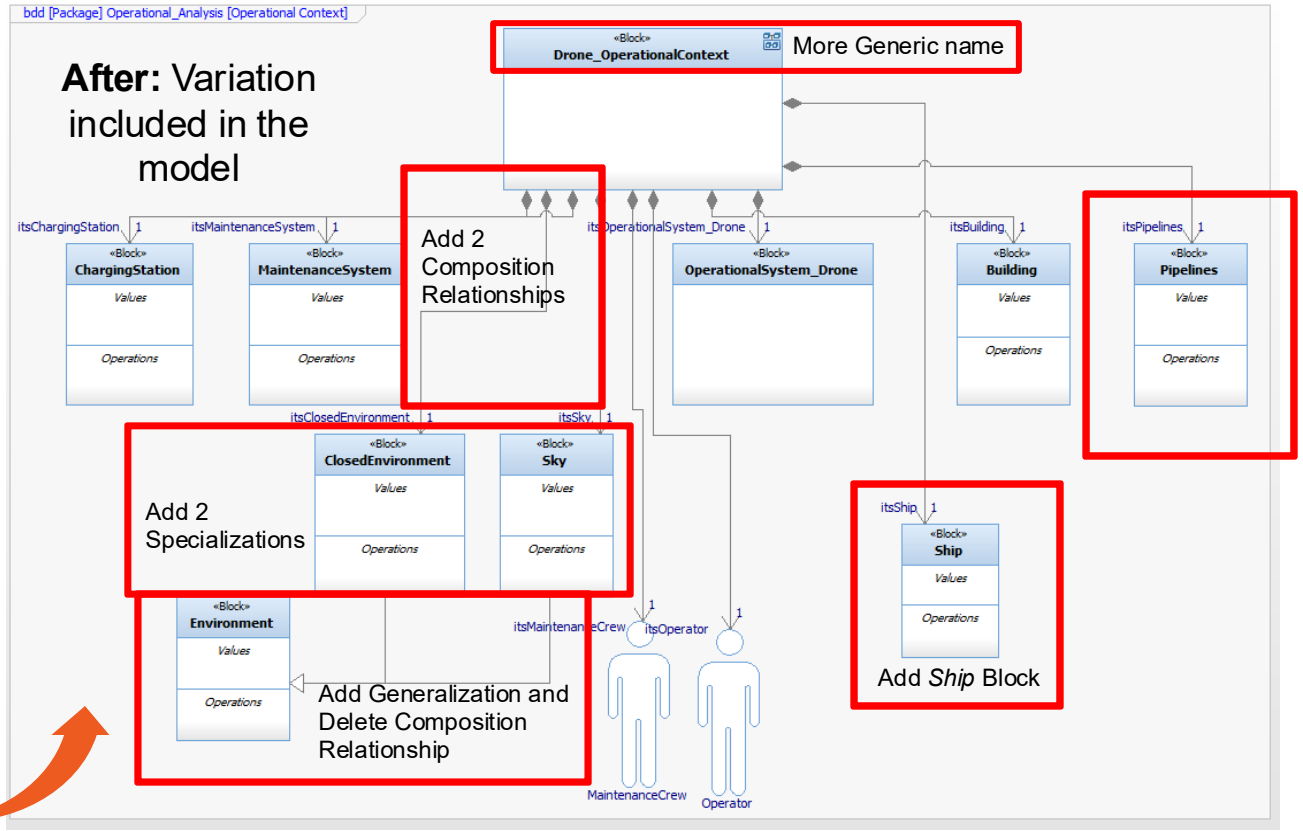


Starting Point:
Modeling a single System of Interest

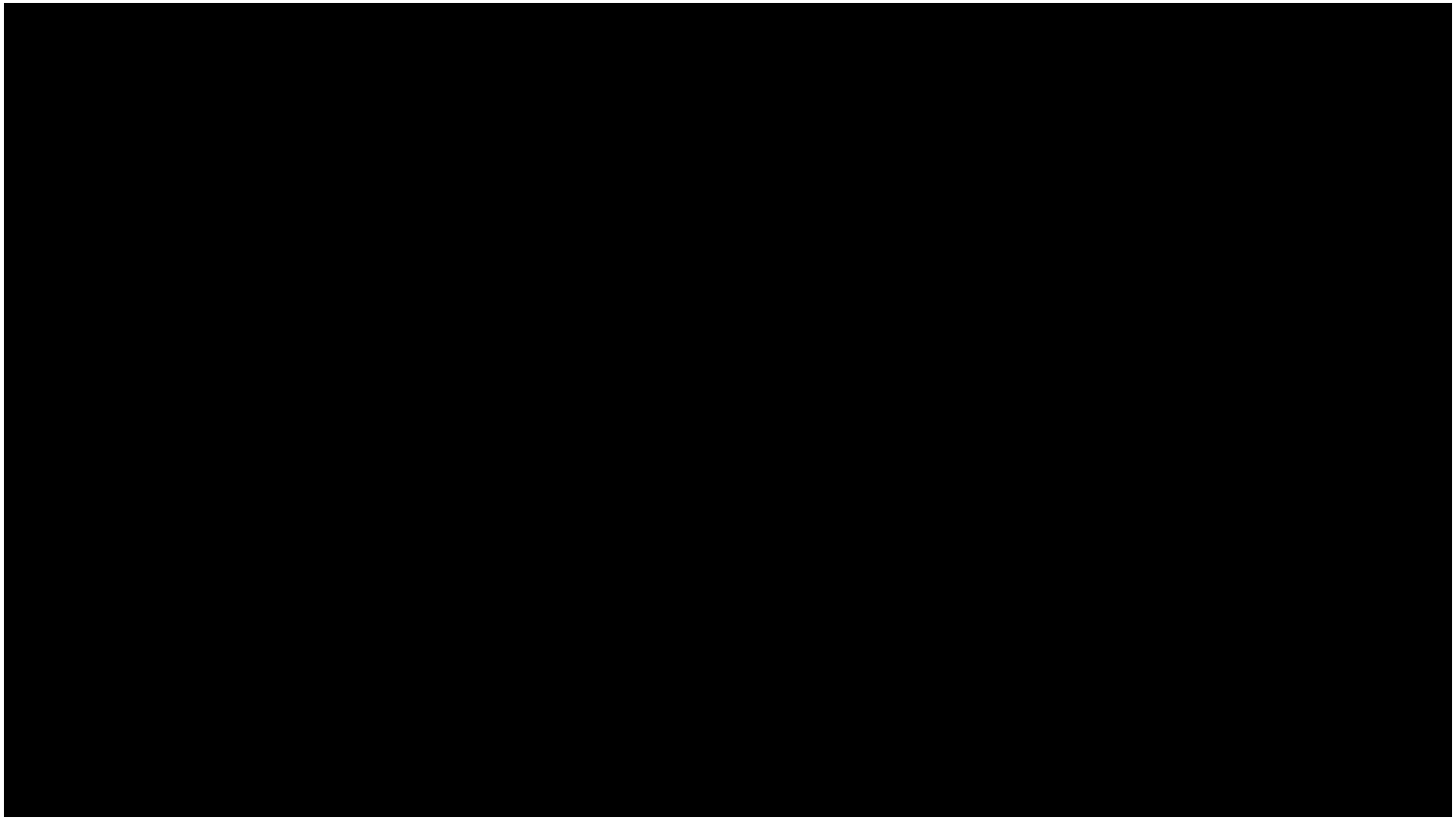
Introducing PLE to MBSE in the Course - Practice

Drone_ProductLine.xfm | *Drone_Configurations

Model Elements	Level	DeliveryDrone	InspectionDrone_Baseline	InspectionDrone_Pipelines
AntiCorrosion_Waterproof	1	☐	☐	☑
Inspection	2	✓	☑	☑
VideoandImageCapture	2.1	☑	☐	☐
InstantHazardDetection	2.2	☒	☐	☑
Payload	3	✓	✓	✓
StandardPayload	3.1	☒	☑	☑
ExtraPayload	3.2	☑	☒	☒
Hovering	4	✓	✓	✓
StandardHovering	4.1	☑	☑	☒
GroundContact	4.2	☒	☒	☑
Range	5	✓	✓	✓
ShortRange	5.1	☒	☑	☒
MediumRange	5.2	☑	☒	☑
Resolution	6	✓	✓	✓
StandardResolution	6.1	☑	☒	☒
HighResolution	6.2	☒	☑	✓
OperatingEnvironment	7	✓	✓	✓
CityDroning	7.1	☑	☑	☐
OpenSpace	7.2	☑	☑	☑
ClosedHazardous	7.3	☐	☐	☑
DroneFrame	8	✓	✓	✓
StandardFrame	8.1	☒	☑	☒
SmallFrame	8.2	☒	☒	☑
BigFrame	8.3	☑	☒	☒



Introducing PLE to MBSE in the Course – An example from the students



Research Design: Analyzing and Adapting MBSE's Education at SIT

a) Qualitative Open-ended Survey

The survey consists of **1 open-ended anonymous question**, focusing on Objective 1 but more generically also on eliciting the challenges they experienced during the learning of MBSE:

What is for you the biggest challenge in learning MBSE?

b) Quantitative Questionnaire Survey

The survey was designed as a one-page online anonymous survey. **A 5-point scale** was used for this question: *Strongly Disagree, Disagree, Neither Disagree nor* Agree, *Agree*, and *Strongly Agree*. **Participants had to select for each challenge one agreement level** to complete the questions, which was mandatory for a survey submission. The questions' section was composed of **six required questions**.

c) Quantitative Comparative Analysis

The course includes three types of assessments: two group assignments and a final multiple-choice test. The first involves modeling a system of the students' choice using an MBSE approach, while the second extends the scope of the same system to a product line, incorporating both the theory and practice of PLE. **The comparison is based on the grades of these assignments, submitted by 10 groups of students.** The group composition remained the same during the two assessments. Grades are assigned on a scale from E to A+.

Findings: Integrating PLE in MBSE academic courses pays off

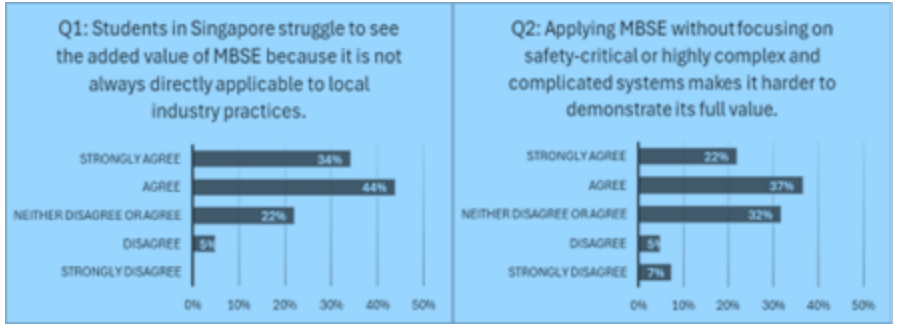
a) Qualitative Open-ended Survey

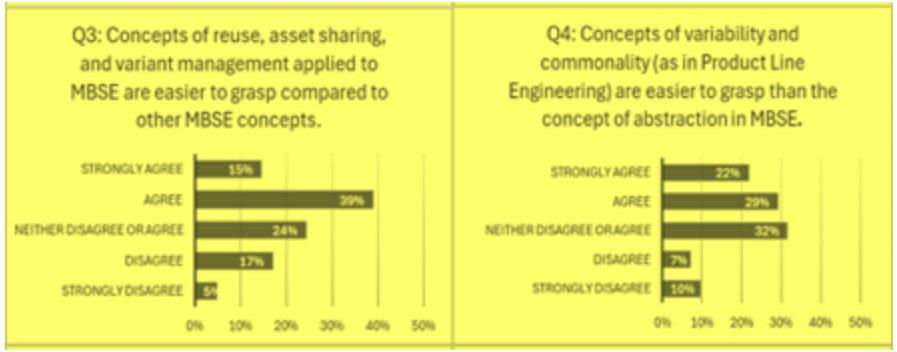
Learning Challenge	Result Percentage
Understanding of MBSE concepts	44%
Application of MBSE	23%
Tedious Discipline	7%
Time Constraint	11%
Teamwork and Collaboration	11%
Tool Limitations	4%

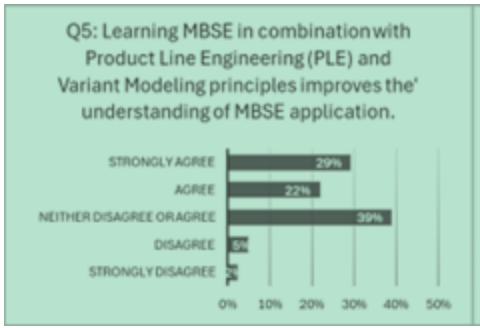
***67% of the students** find **difficult to understand MBSE** concepts and apply them*

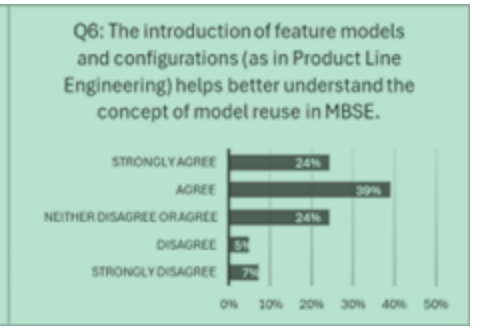
Findings: Integrating PLE in MBSE academic courses pays off

b) Quantitative Questionnaire Survey









Above 50% "Agree" or "Strongly Agree" *with the statement of* ***Questions 3, 4, 5 and 6!***

Important: At the time of the survey completion, the students were dealing for 2.5 months with the MBSE concepts and only 3 weeks with the newly introduced concepts.

Findings: Integrating PLE in MBSE academic courses pays off

c) Quantitative Comparative Analysis

Grade Range	Assignment 1 (only MBSE)	Assignment 2 (MBSE + PLE)
A+	0 groups	3 groups
A	1 group	0 groups
A-	2 groups	3 groups
B+	4 groups	3 groups
<B+	3 groups	1 group

A comparison of the grades between Group Assignment 1**, which focused exclusively on the application of **MBSE, and Group Assignment 2,** which integrated **MBSE with PLE**, reveals a **significant improvement** in performance for the **second assignment

Important: One could argue that the improvement might stem from students having more time to practice and learn from their mistakes between assignments. However, this factor is counterbalanced by the challenge of mastering and applying PLE concepts in just three weeks for Assignment 2

Conclusion, Limitations and Future Work

Conclusion

Students in Singapore struggled to understand and apply MBSE, particularly its industrial value. However, **introducing PLE** late in the course significantly **improved MBSE application and understanding**, especially through concepts like feature models and reuse, which resonated with local industry needs focused on variability.

Limitations

The study was **limited to one course**, with **PLE introduced** only **in the final month**. **Reduced attendance** and **uneven survey response rates** may affect findings. **Improved grades** may also reflect growing **familiarity with MBSE**, not solely the impact of PLE.

Future Work

Expand the study to similar regions (e.g., Southeast Asia, Latin America) **and mature engineering nations** (e.g., US, China, Europe) to validate generalizability and explore broader **educational integration of PLE with MBSE**

Presentation

WE WILL BE PRESENTING AT THE

INCOSE INTERNATIONAL SYMPOSIUM 2025:

A Survey on MBSE Adoption Challenges in the INCOSE Asia and Oceania Sector

Location
Ottawa, Canada

Date
30 July 2025

Time
15:30H–15:55H

Join us and **explore** whether Model-Based Systems Engineering (MBSE) **Adoption Challenges** in the **Asia Pacific** Region differ from other regions!

Find out more about the event: IS2025

#IS2025 #INCOSE #SystemsEngineering #PLE

Presenters


Mohammad Chami
SysDice


Marco Forlingieri
PTC


Dr. Quoc Do
Frazer-Nash

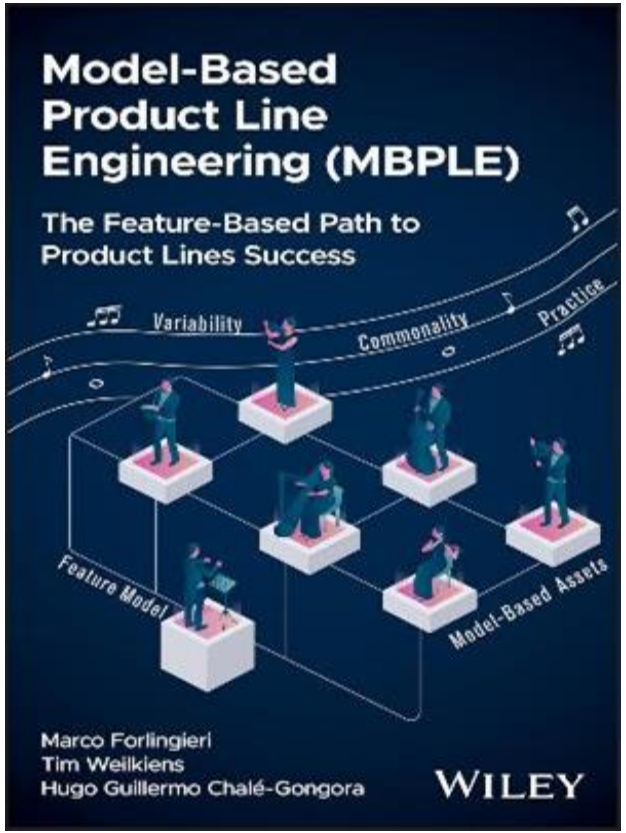

Habibi H. Arifin
Dassault Systemés

If you are interested in MBPLE..

AIRBUS MBDA MISSILE SYSTEMS THALES

Raytheon An RTX Business BELIMO

Thank You
Question Time!



LOCKHEED MARTIN ptc

PRODUCT LINE ENGINEERING IN ACTION

Master complexity and deliver at scale

Week of October 20th

Lockheed Martin Facility, Orlando, FL

Stay tuned for more details and registration information.

- Join fellow architects, software, and systems engineers for a PLE User Group to hear expert insights and best practices from industry leaders.

35th Annual INCOSE international symposium

hybrid event

Ottawa, Canada
July 26 - 31, 2025