34th Annual INCOSE international symposium

hybrid event

Dublin, Ireland
July 2 - 6, 2024

Robert Hällqvist, Erik Herzog, Johanna Wallén Axehill, *Saab Aeronautics*
John R. Palmer, *The Boeing Company*

Excuse me Sir/Madam, which Model?

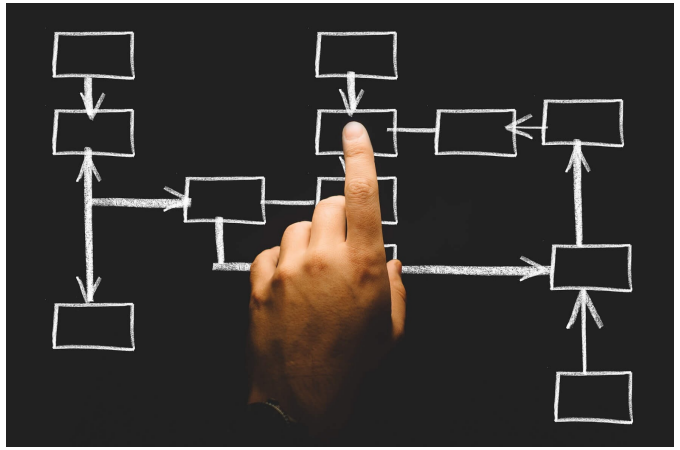
The main messages

1

Why **one single model is not enough** to capture every aspect of a system throughout its development

2

The **need for a unified nomenclature**, covering all phases and usages of models



Boeing & Saab

Some of our products

Boeing 787

Gripen E

T-7A

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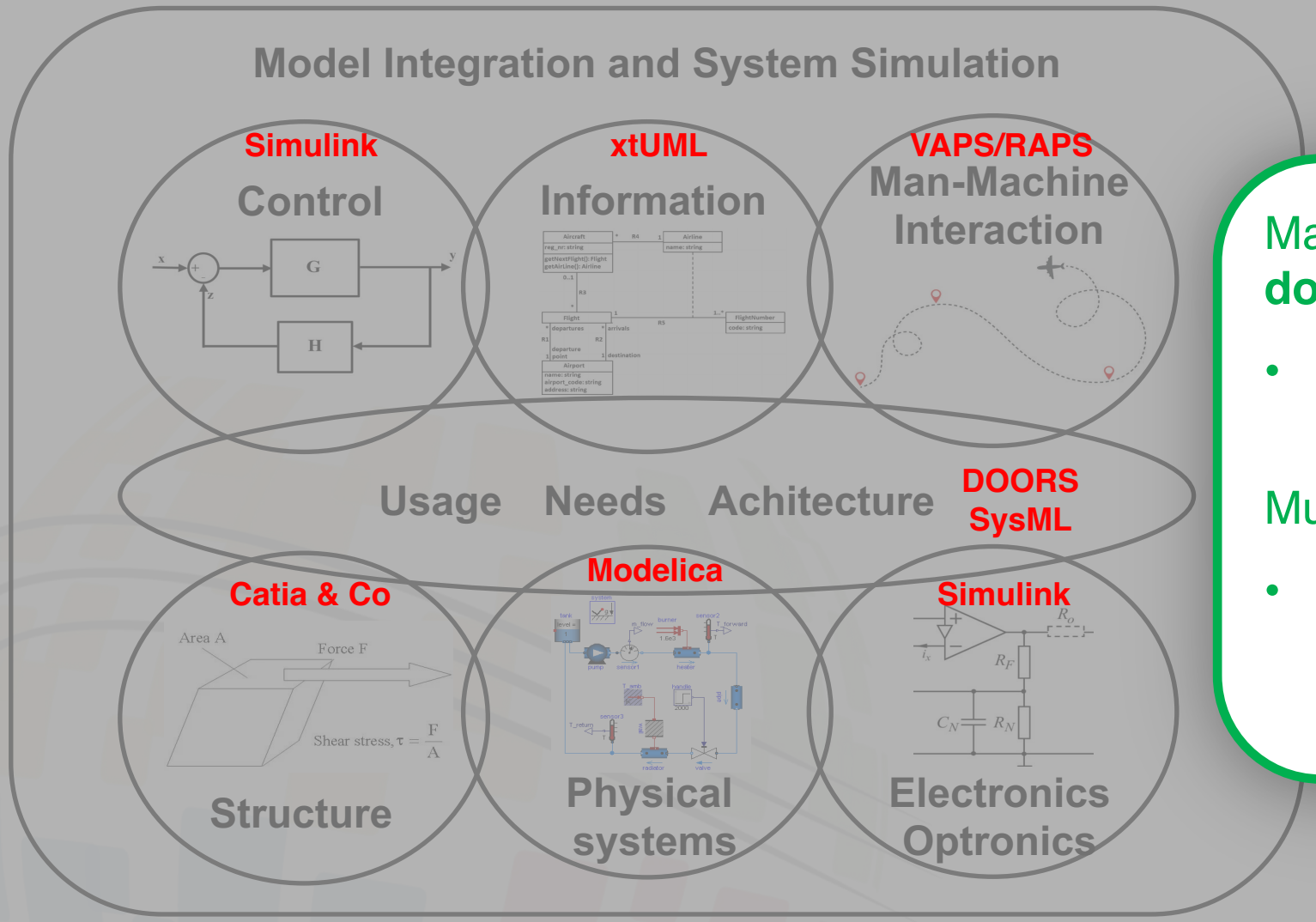
Background MBSE Domains – Gripen example



Many **different languages and domains**

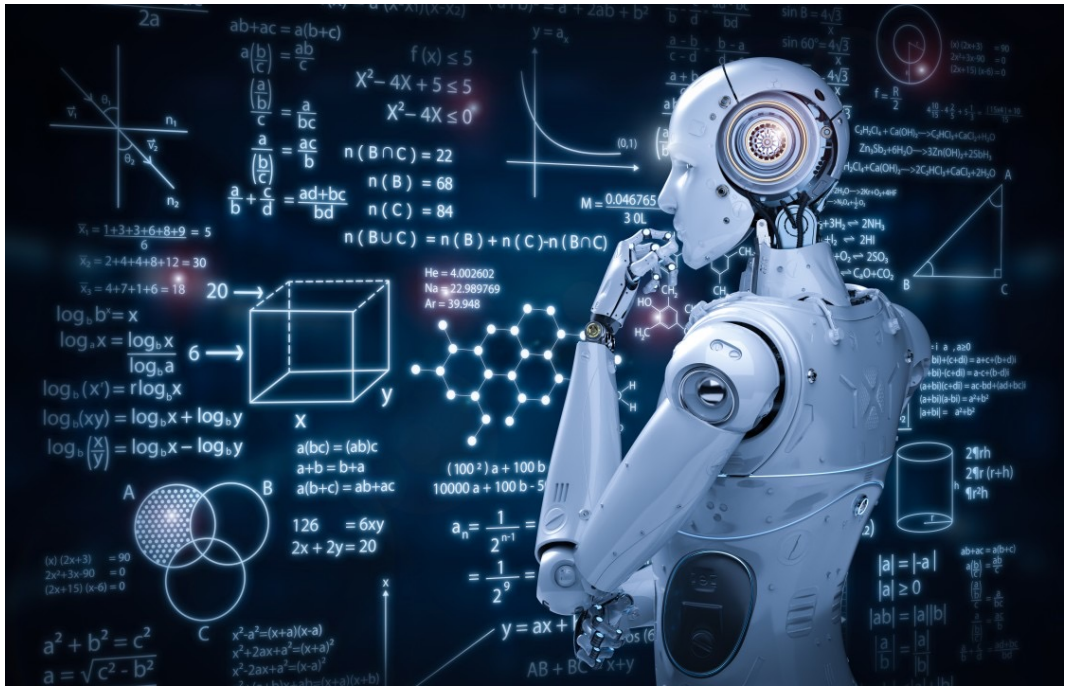
- Clearly defined purpose for each model

Multiple **interrelated models**

- Need for configuration mechanisms throughout all lifecycle phases

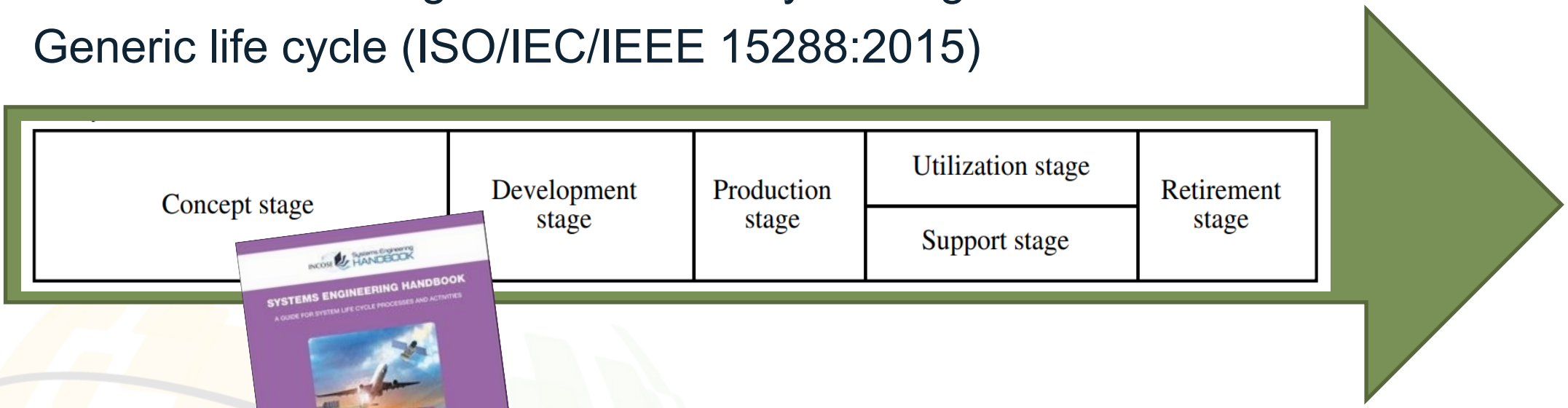
Models – drivers for multiplicity

- **Model purpose**
  - Aggregate purposes increase model complexity and maintenance costs
- **Model tense**
  - Information capturing the desired future state fits poorly with information capturing the present
- **Model fidelity**
  - Select the right model for the right task
- **Modeling domain**
  - Select the right language for the right purpose
  - Need the ability to integrate 3rd party models



Modelling and simulation today at Saab

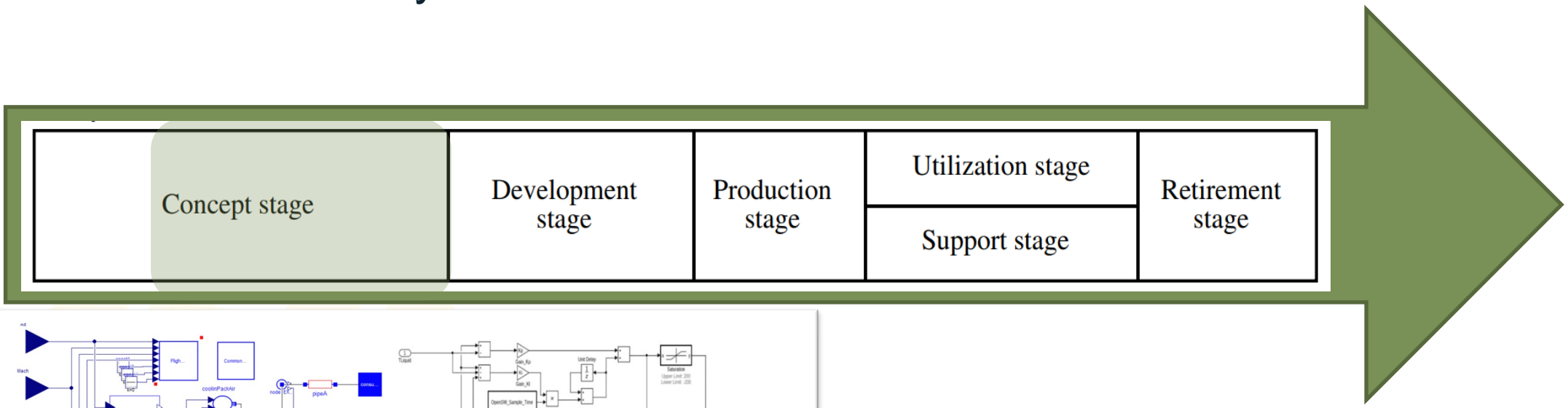
- Used to various degrees in a all lifecycle stages
- Generic life cycle (ISO/IEC/IEEE 15288:2015)

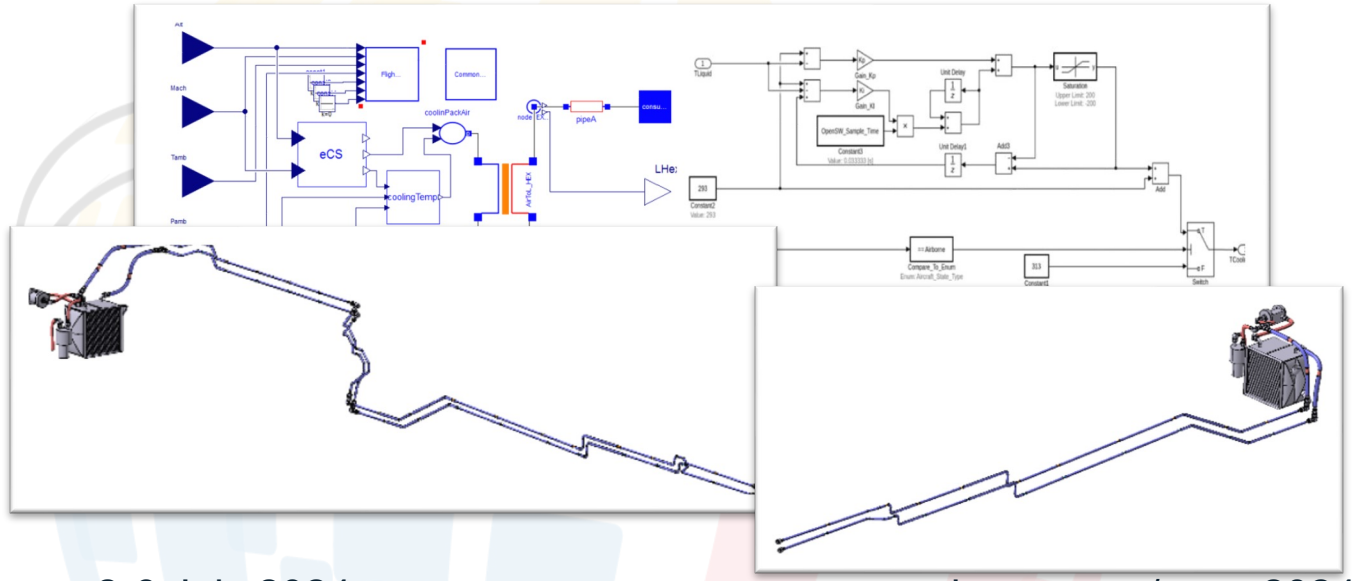


INCOSE. Systems Engineering Handbook:
A Guide for System Life Cycle Processes and Activities.
Fifth Edition, Wiley

Modelling and simulation today at Saab

- Evaluation of subsystem architectures

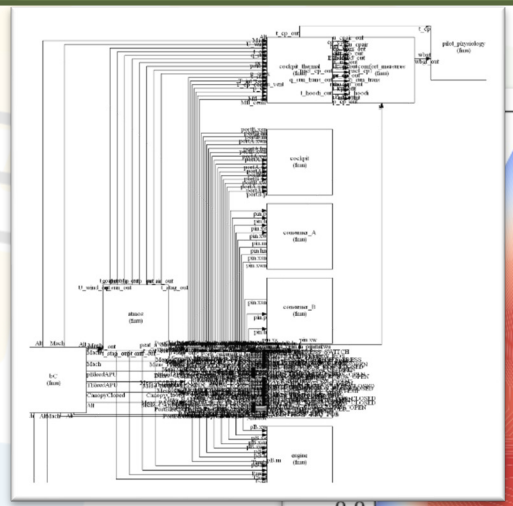


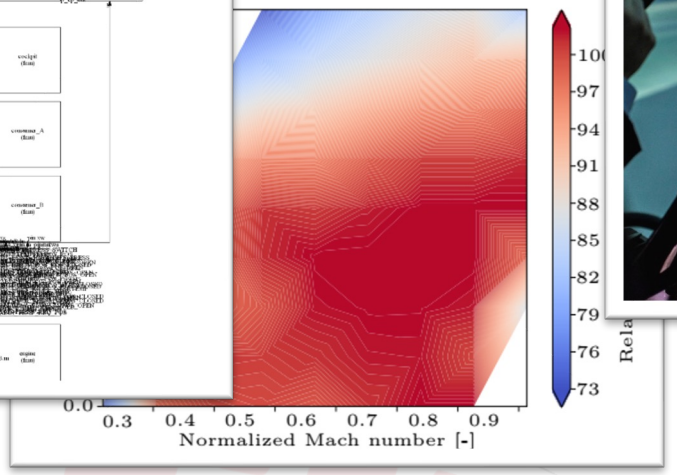


Modelling and simulation today at Saab

- Support hardware and software design

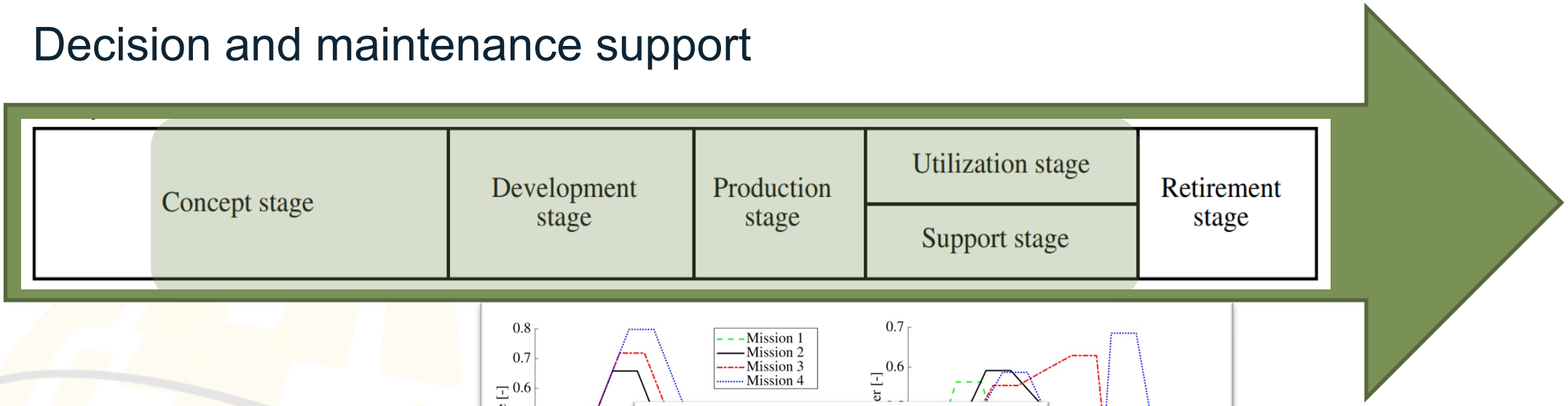
Concept stage	Development stage	Production stage	Utilization stage	Retirement stage
			Support stage	

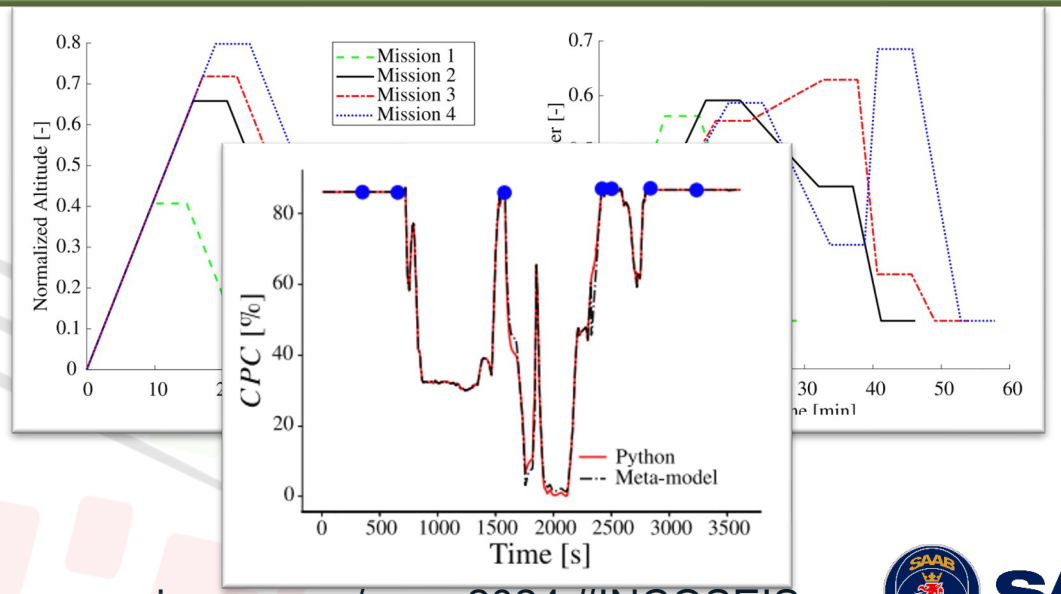




Modelling and simulation today at Saab

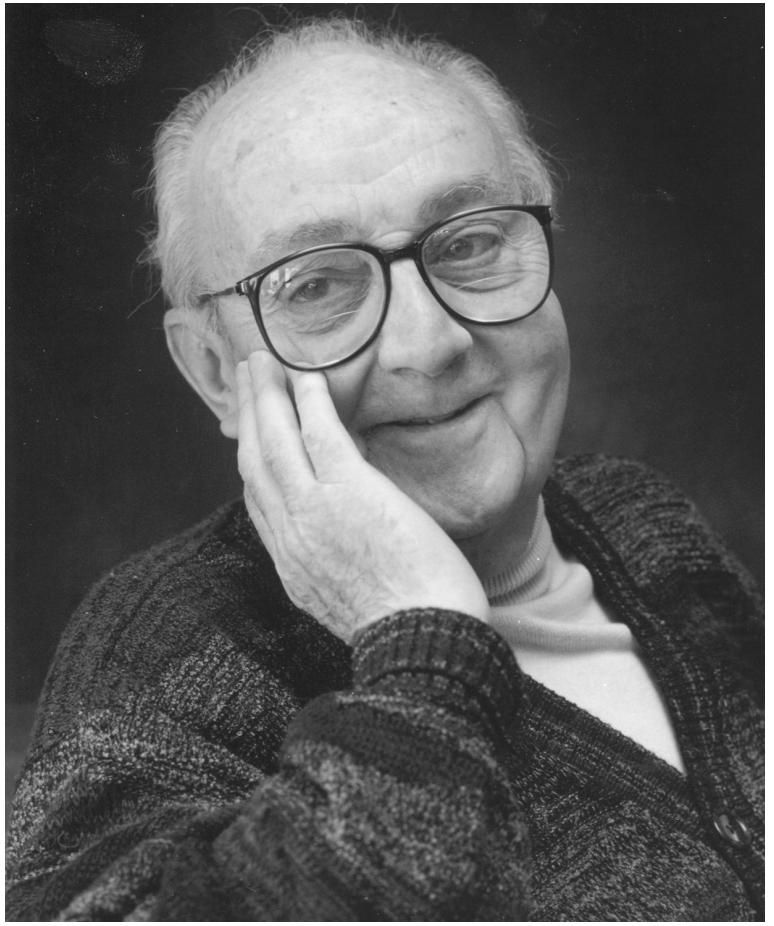
- Software & hardware verification
- Decision and maintenance support





All models are approximations.

Essentially, all models are wrong but some are useful.



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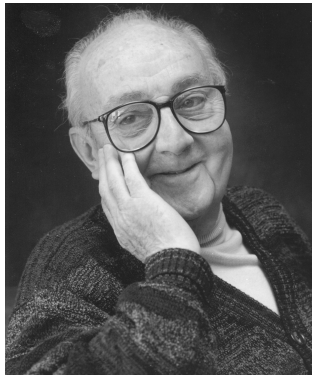
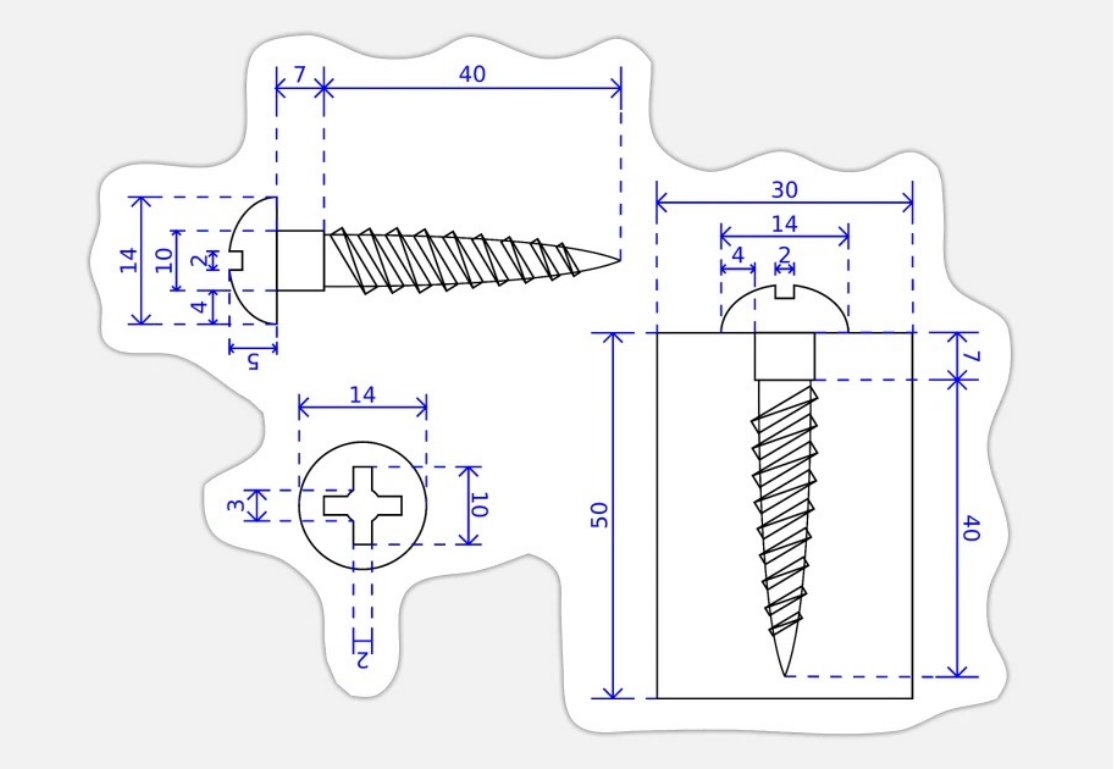
Some words on Credibility

- All models are developed to fulfil some purpose – often not caputerd explicitly
- **Credibility:** The extent to which the model meets its purpose
- Models, whose credibilty is unknown is of questionable value

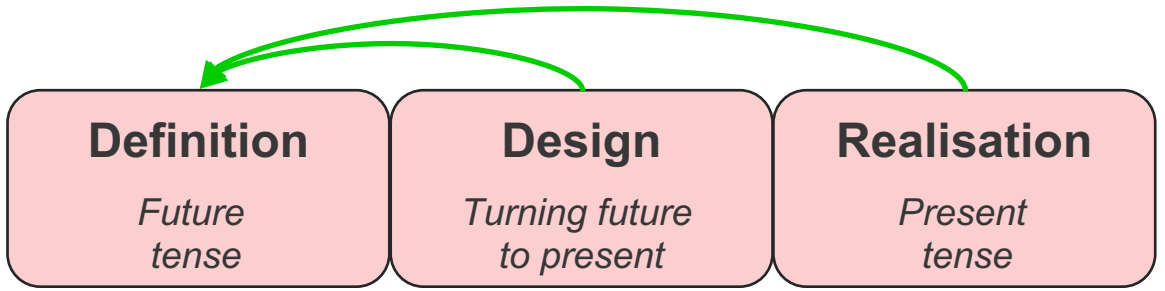
Credible models are useful!



Models capturing different views on a system



Proposed model framework



Definition model

- Captures the **intended architecture**
- Relatively undetailed
- Used for communication and long-term memory, e.g. change management/development planning
- For example, SysML as a common language

Design model

- Captures a system element from a **particular perspective**
  - Design or analysis focus
  - Interfaces and key properties
- **Multiple** Design models may be required to adequately represent the intent in a Definition model
- Multiple languages, e.g. Simulink, Modelica, CFD

Realisation model (physical/virtual)

- **Multiple virtual** Realisations with different **fidelities** and **perspectives** may be created
- **Interface models** are required for both an executable realisation and a realisation of the physical system

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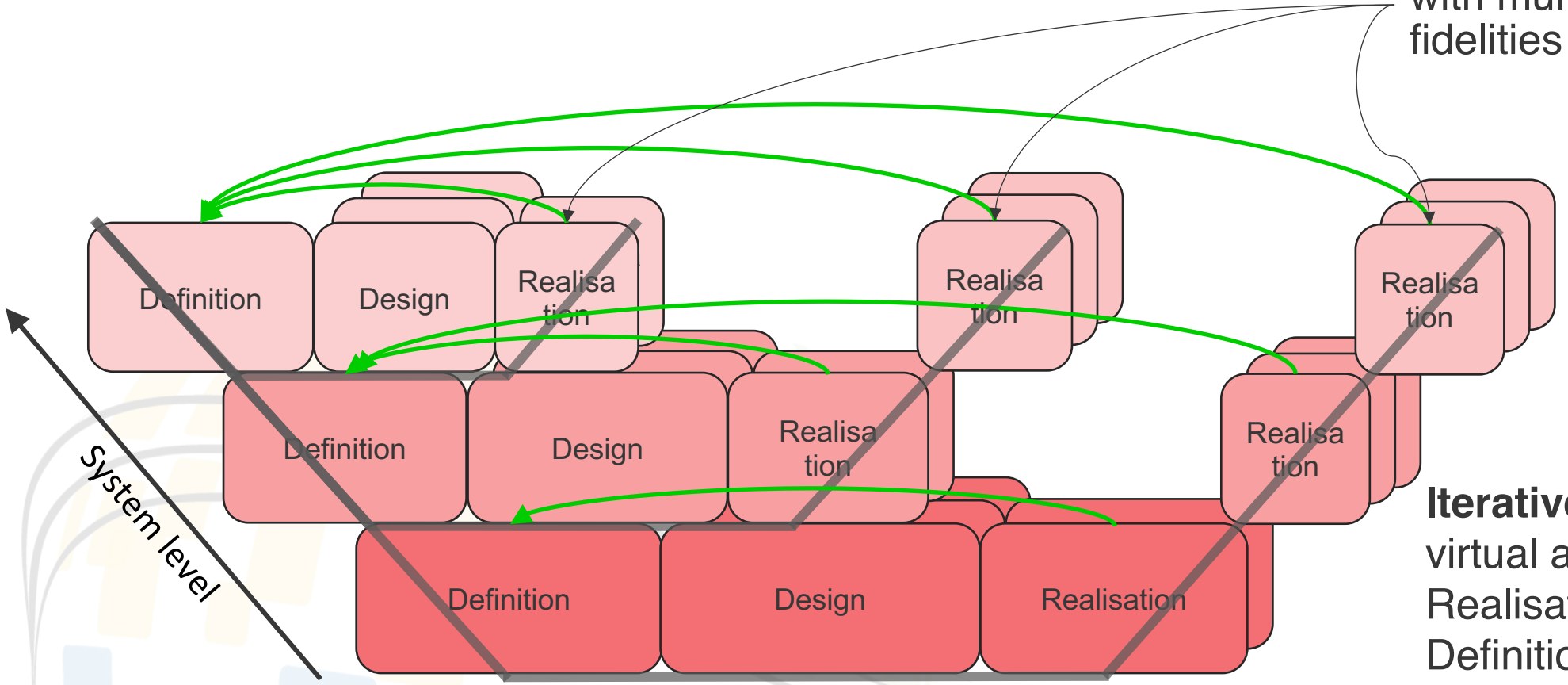
Feedback using virtual Realisations

Multiple virtual Realisations with multiple perspectives, fidelities and credibilities

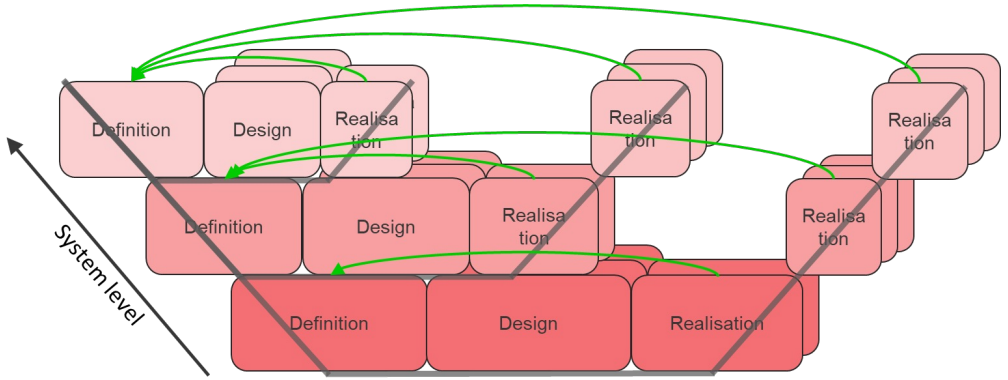


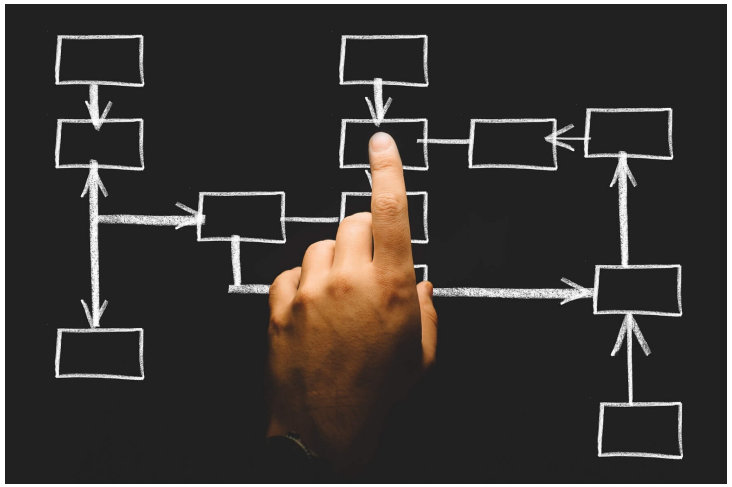
Iterative feedback from virtual and physical Realisations to shape the Definition and Design models

Problem statement

- We have a conceptual model
- Need to define
  - Clear definitions for different model types used in development
  - Explicit expectations on each model type

- There is a need for a unified terminology!
  - Not just within Saab





A Saab view on model types terminology

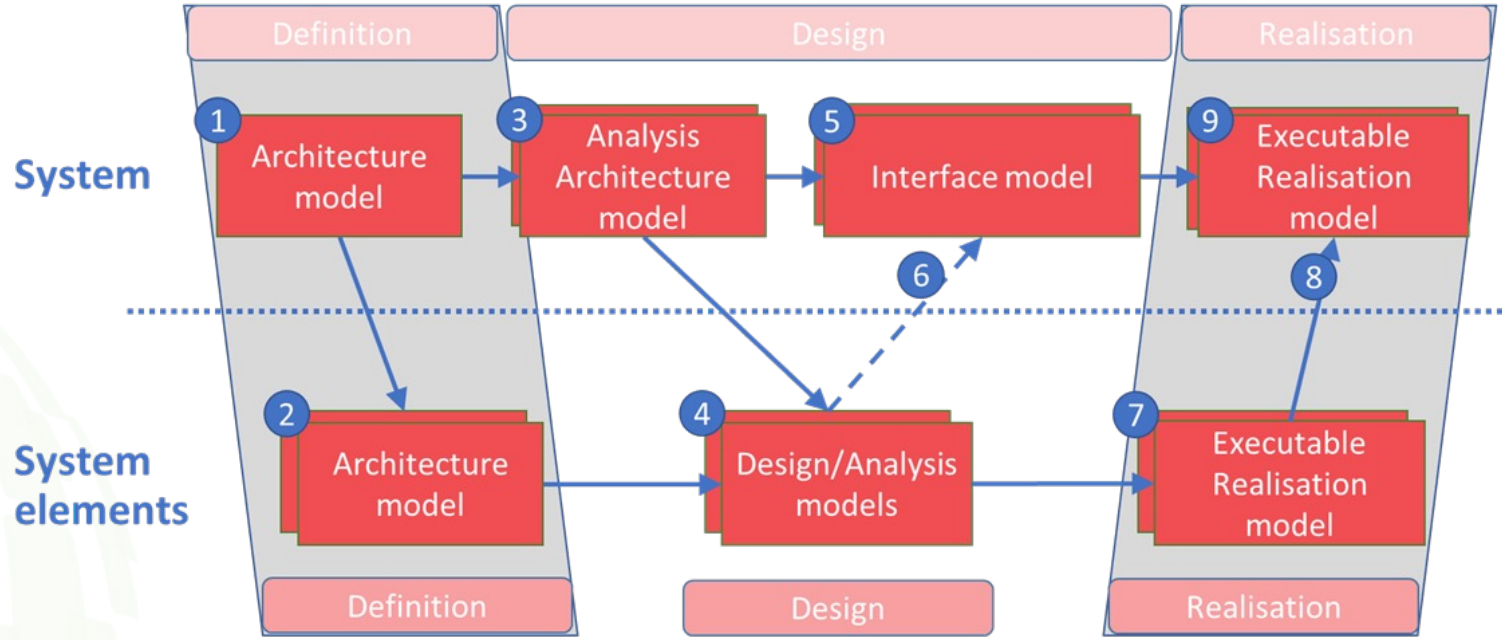
Tenses and model types

Architecture model

- Identifying system behaviour, system elements and interfaces

Analysis Architecture model

- Adapting the architecture for a particular analysis purpose
- May result in the addition or deletion of items compared to the architecture model



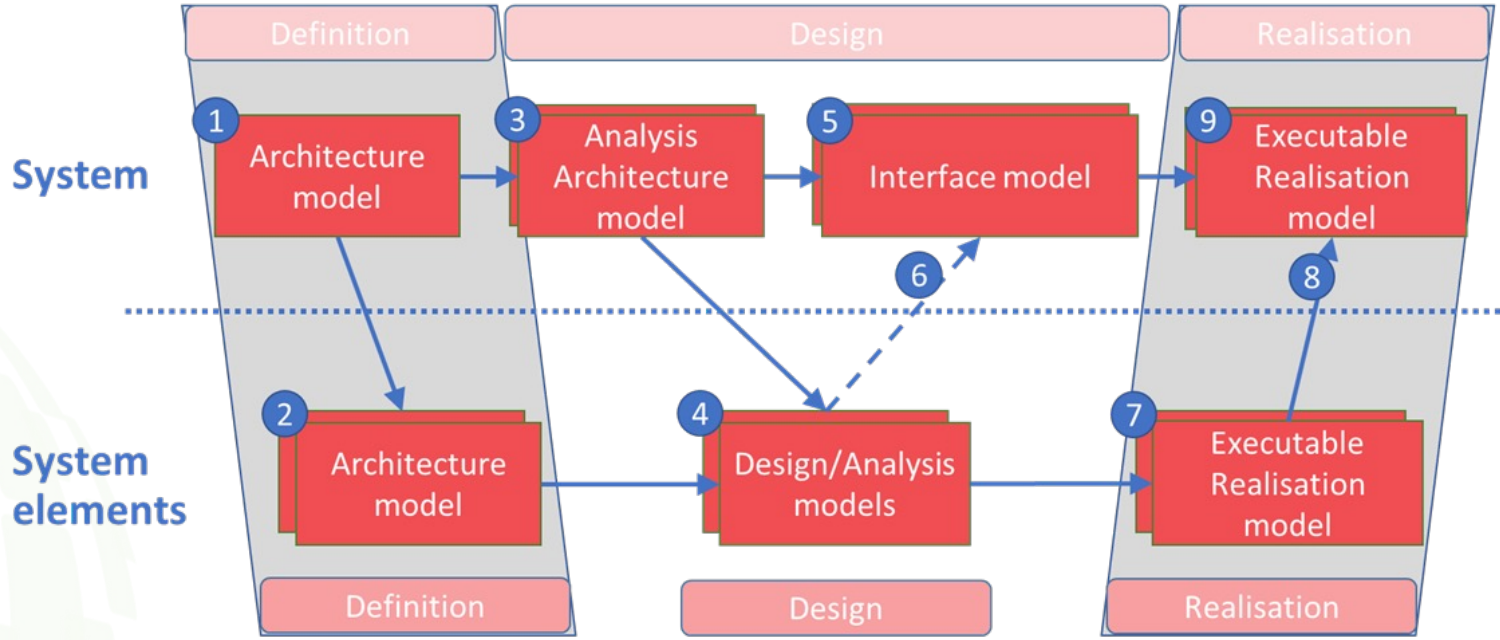
Tenses and model types

Design/Analysis model

- Captures the emergent system design or system analyses

Interface model

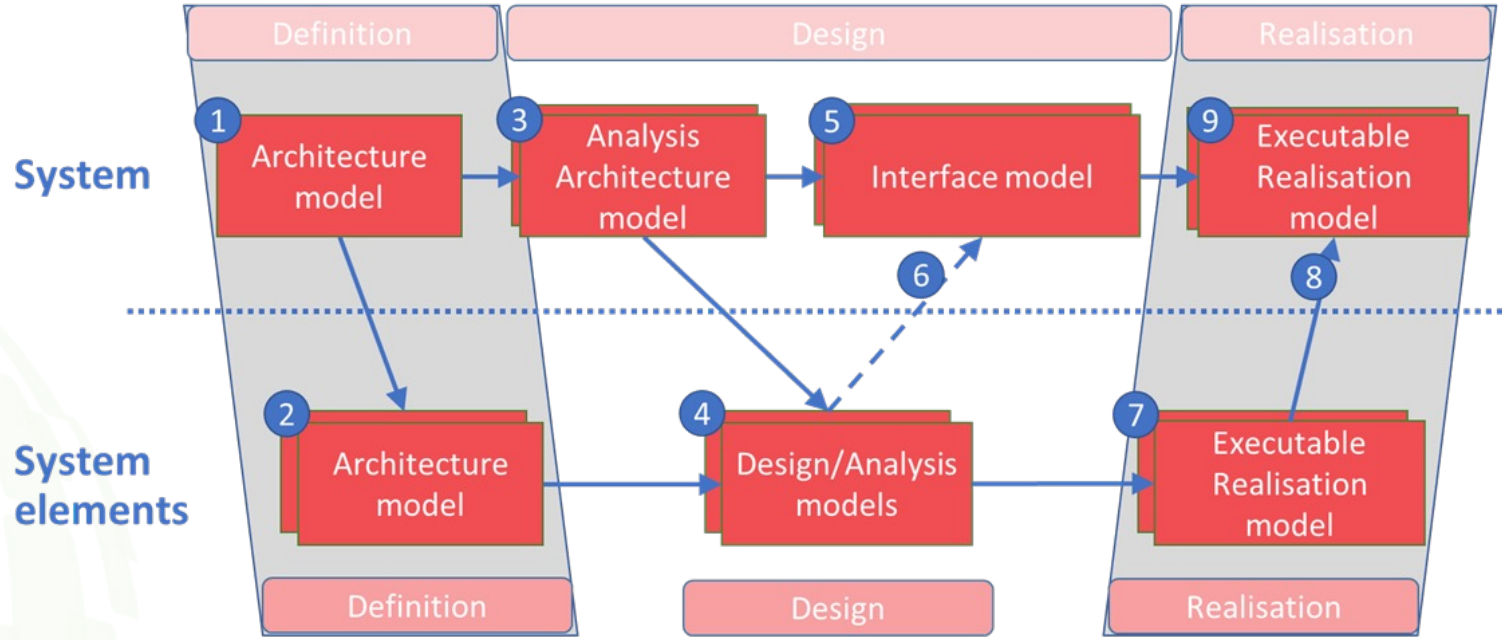
- Derived from the Architecture model and refined with design content
- Purpose to provide the template for virtual and/or physical integration



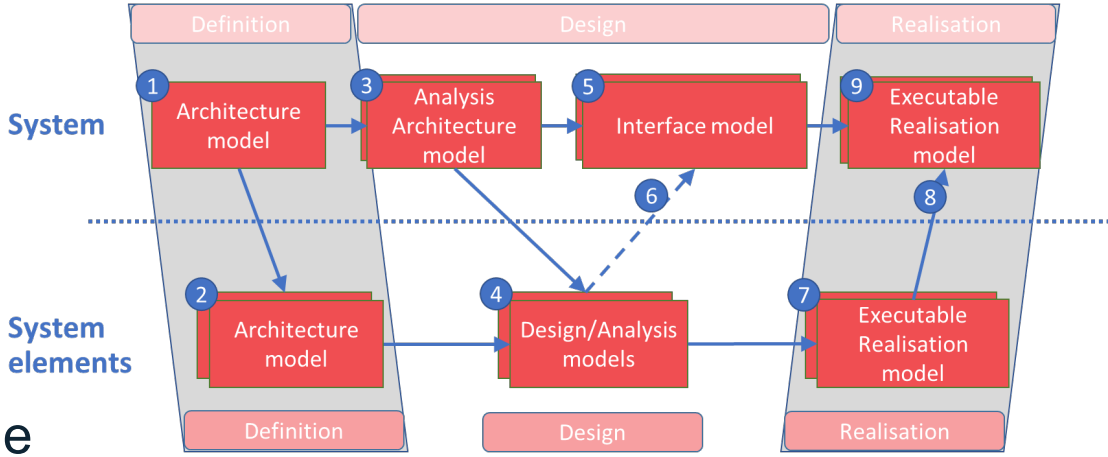
Tenses and model types

Executable Realisation model

- The virtual realisation of a system used for gaining insights and knowledge



Why separate models?



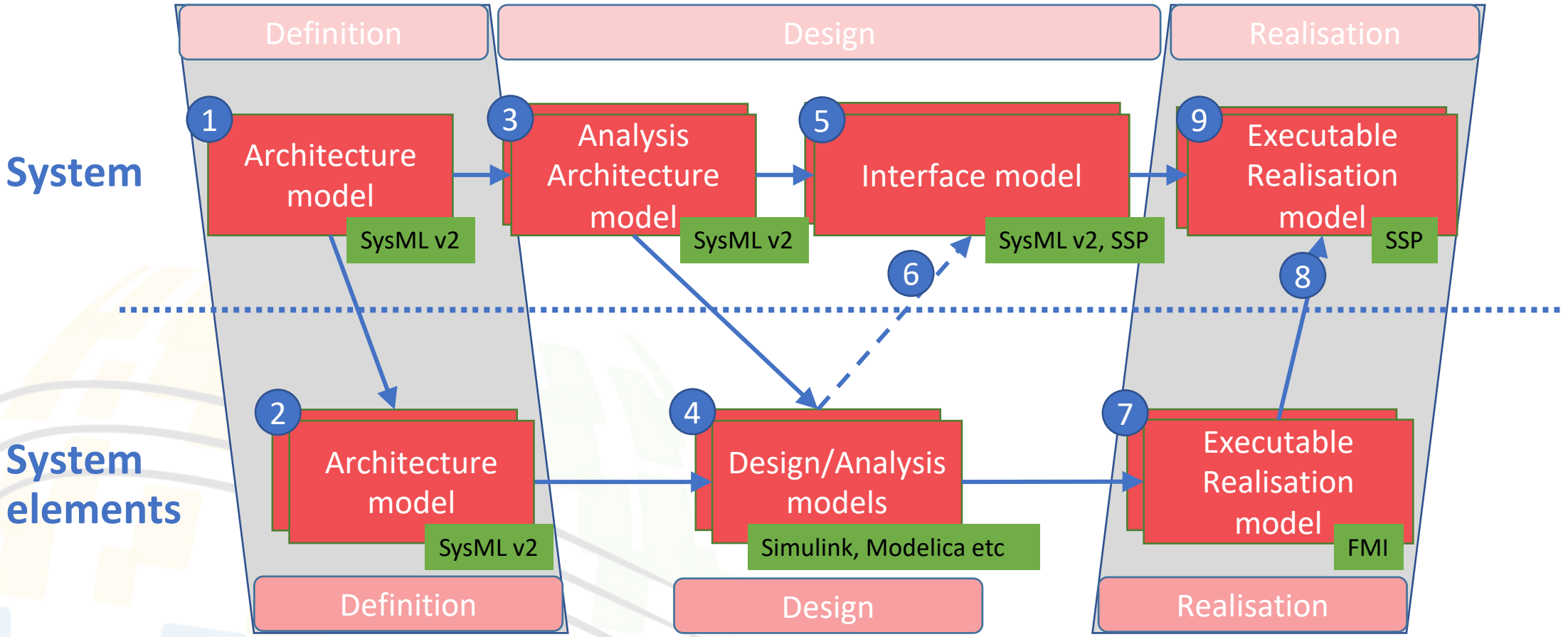
- **Architecture model:** Overall definition of the system – suitable for communication, not executable
- **Analysis Architecture model:** Meeting the needs for a particular analysis – based on the architecture but should not be included in it
- **Design/Analysis model:** Allowing the most appropriate modelling language for detailed design of a heterogeneous system
- **Interface model:** Detailed interface definition – in a langauage agnostic format for integration and creation of Executable Realisation models.

Analysis Architecture models can not be merged with the **Architecture model** as it would skew the Architecture model

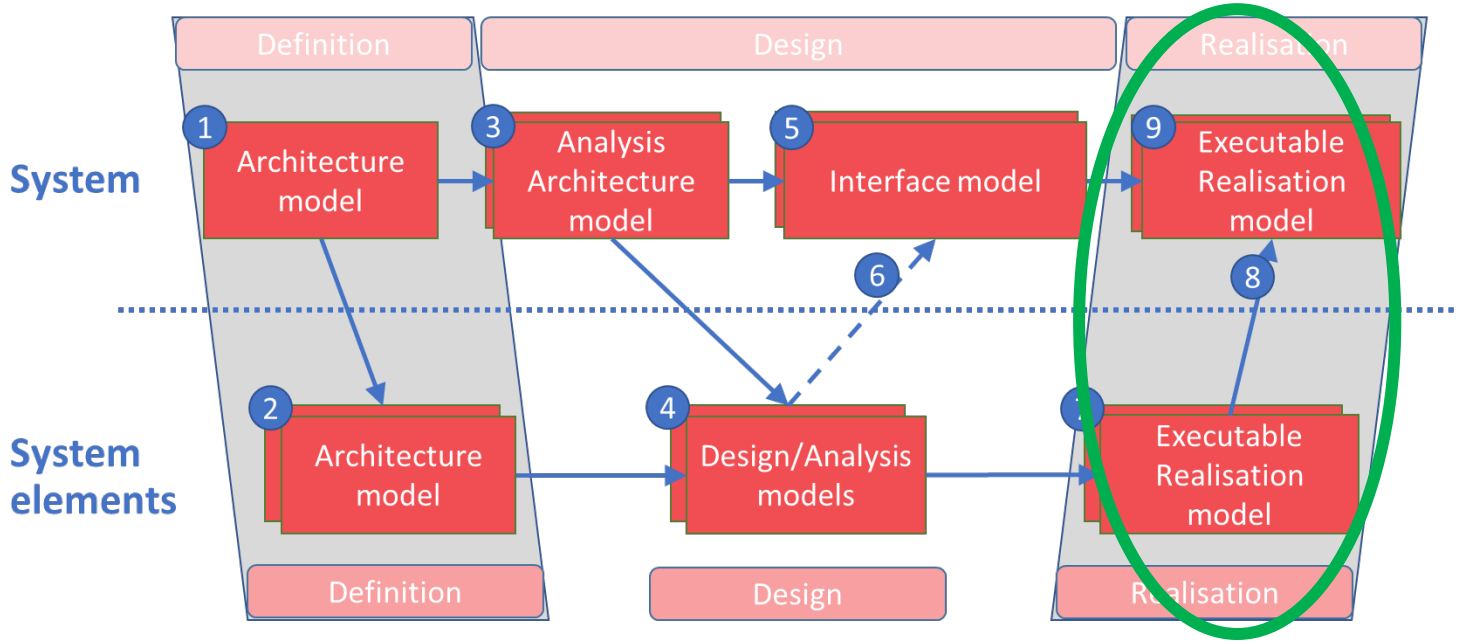
Design/Analysis models are there to take advantage of the power of domain specific languages

Interface models are distinct to allow interface refinement without having to change the **Architecture or Analysis Architecture models**

Tenses and model types



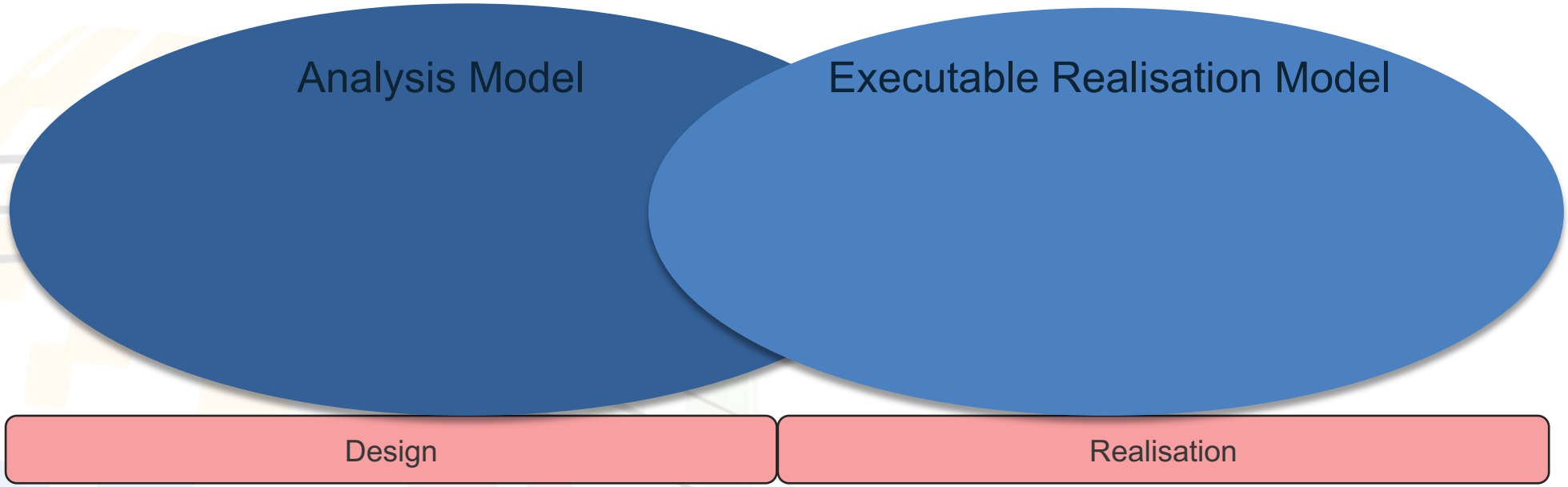
Nomenclature for executable models



Executable Realisation Model

A **digital artifact** that an experiment can be applied to in order to answer **questions about a corresponding physical logical artifact** (realised or not).

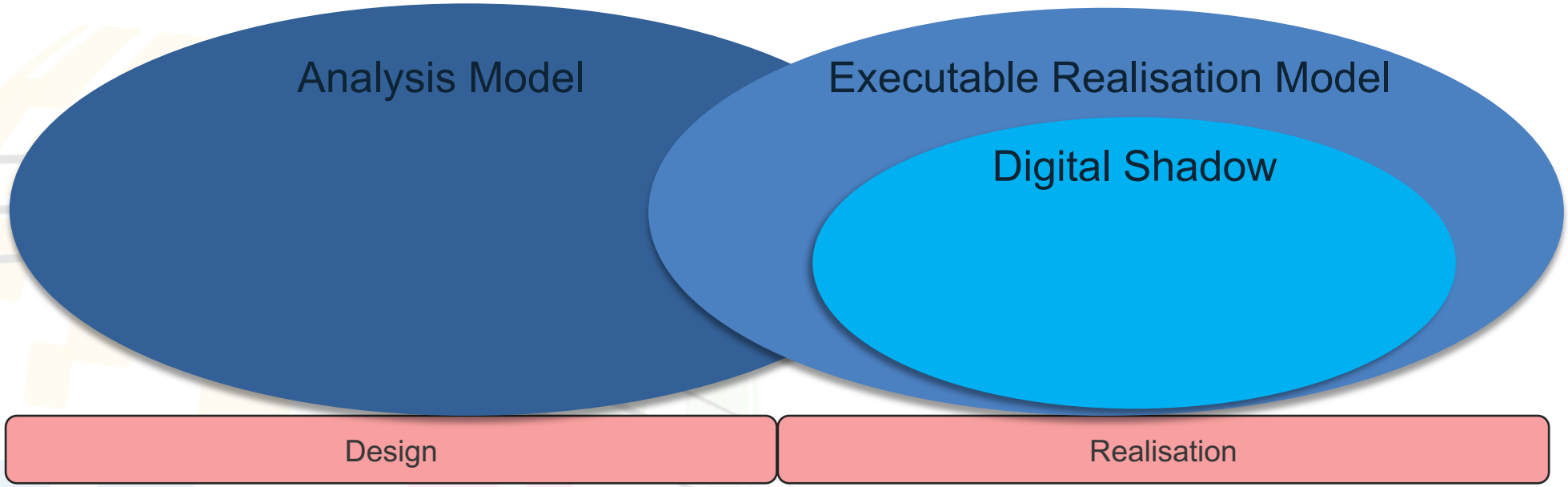
- *Example:* **A control system simulation model**, used in a system simulator during development **of a specific product configuration**.



Digital Shadow

An **Executable Realisation Model** where relevant **information from the physical space is incorporated automatically**. ***Passive*** in the sense that it does not automatically influence the actual system it represents.

- *Example:* A model processing aircraft maintenance information, received automatically from the aircraft during or after flight.



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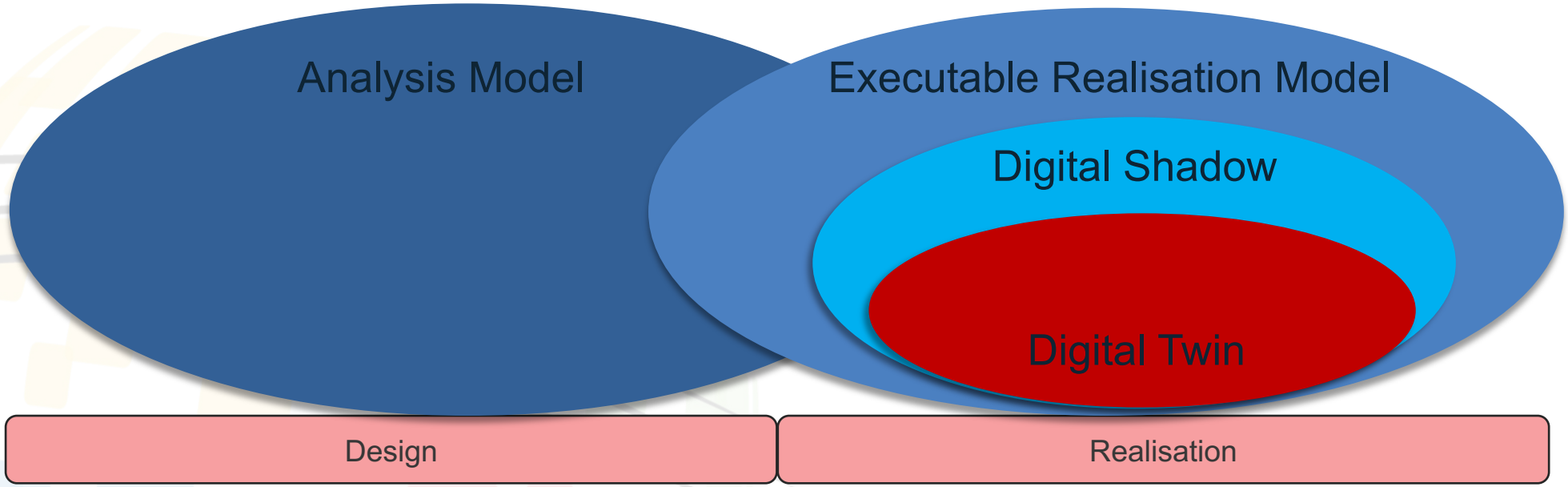
Digital Twin

Executable Realisation Model where **any relevant bi-directional flow of information** between the virtual and physical spaces is **exchanged automatically**. The Digital Twin is ***Active***.

- *Example:* A model used during equipment test, where software parameters in the equipment are changed automatically based on the information analysed.



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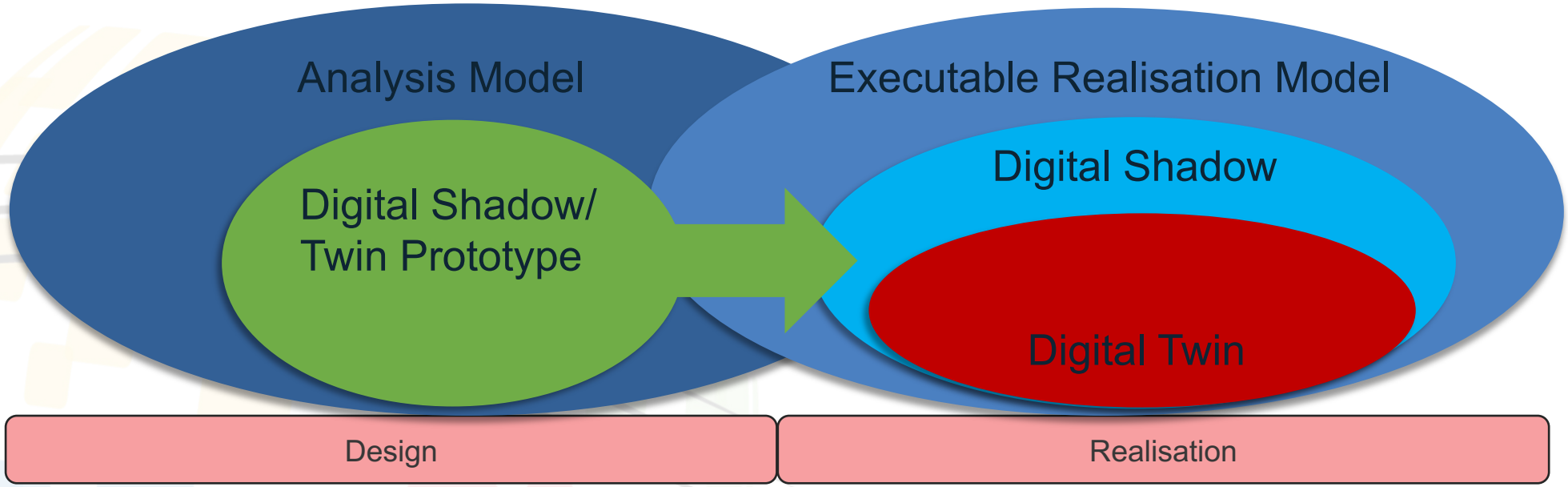
Digital Shadow/Twin Prototype

Analysis Model or Executable Realisation Model that is **identified as a candidate** to evolve to a Digital Shadow or Twin. Contains the structure and information necessary to create Digital Shadows or Twins if decided to do so.



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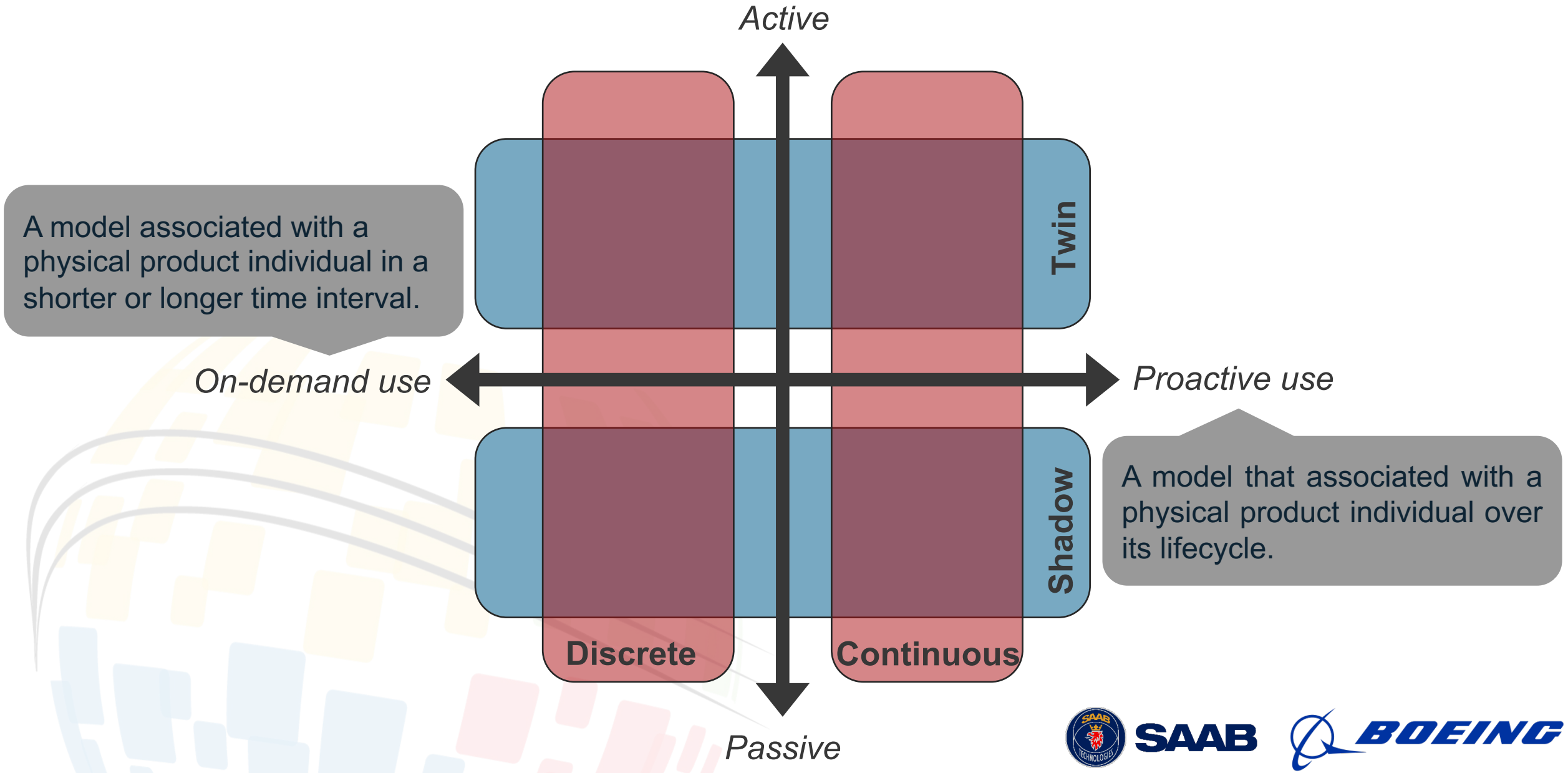
Two more dimensions



A model associated with a physical product individual in a shorter or longer time interval.

A model that associated with a physical product individual over its lifecycle.

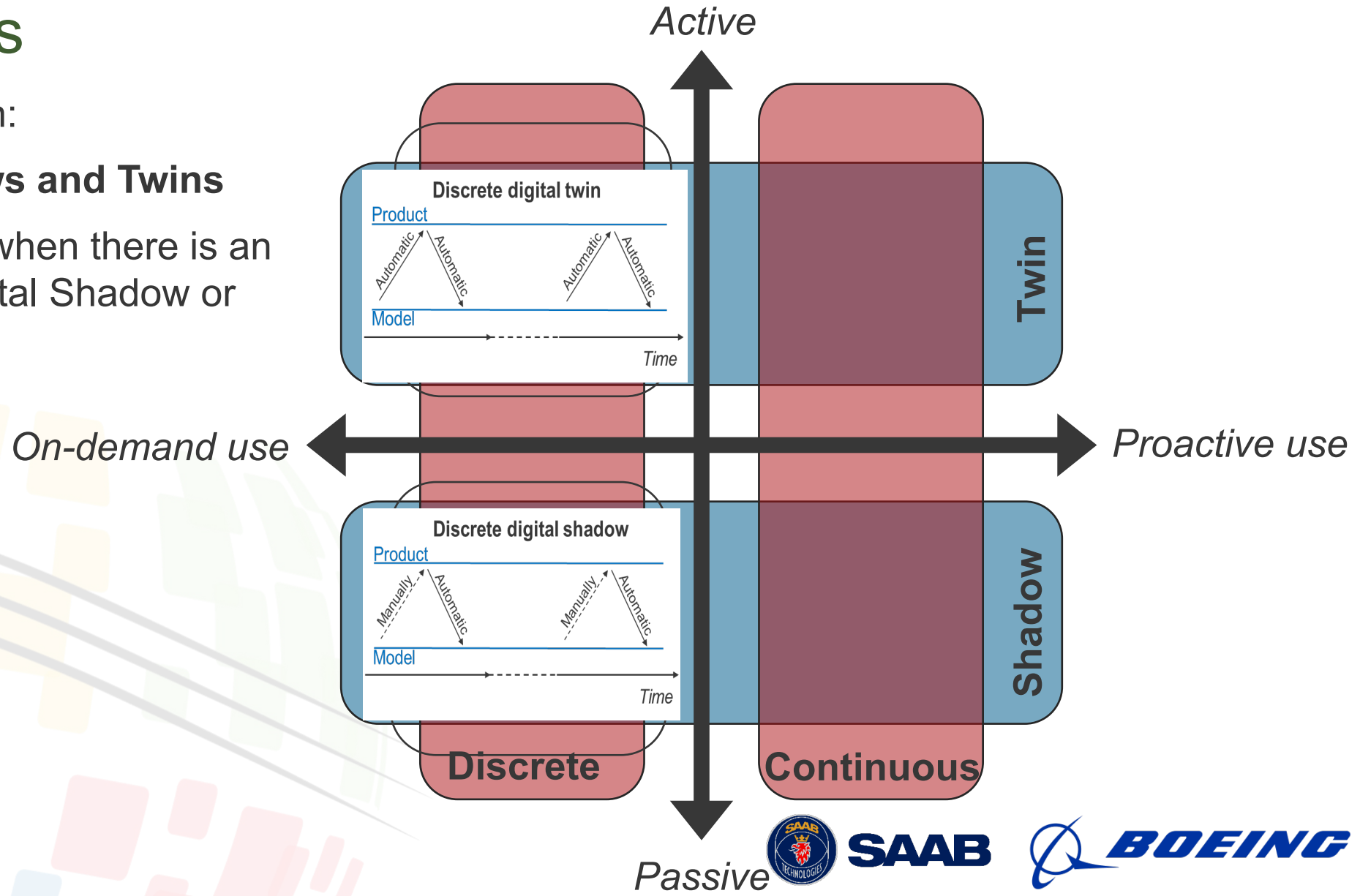
Digital Shadows and Twins

Use categories

On-demand use results in:

Discrete Digital Shadows and Twins

- Maintained and used when there is an explicit need for a Digital Shadow or Twin



Digital Shadows and Twins

Use categories

On-demand use results in:

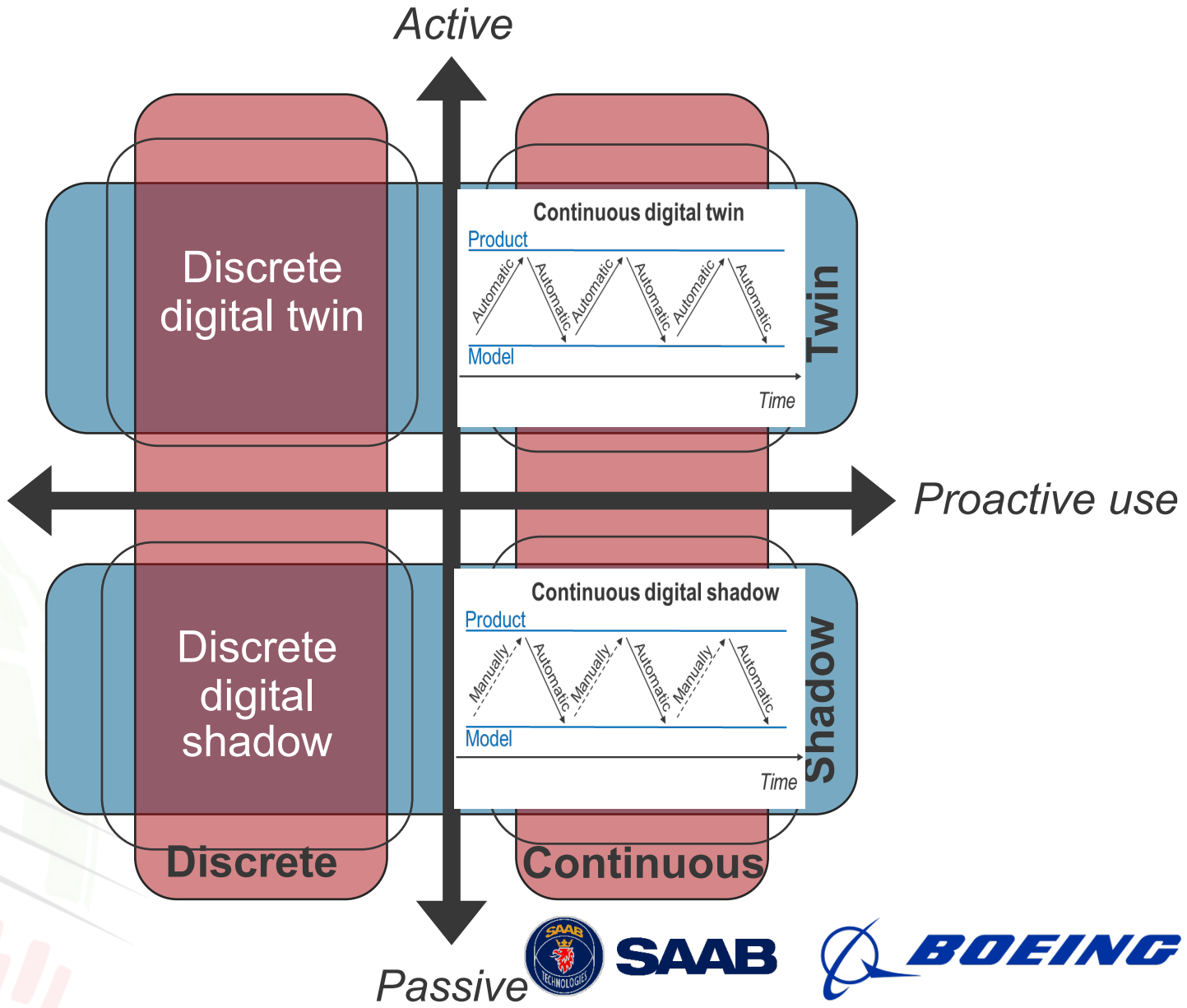
Discrete Digital Shadows and Twins

- Maintained and used when there is an explicit need for a Digital Shadow or Twin

Proactive use results in:

Continuous Digital Shadows and Twins

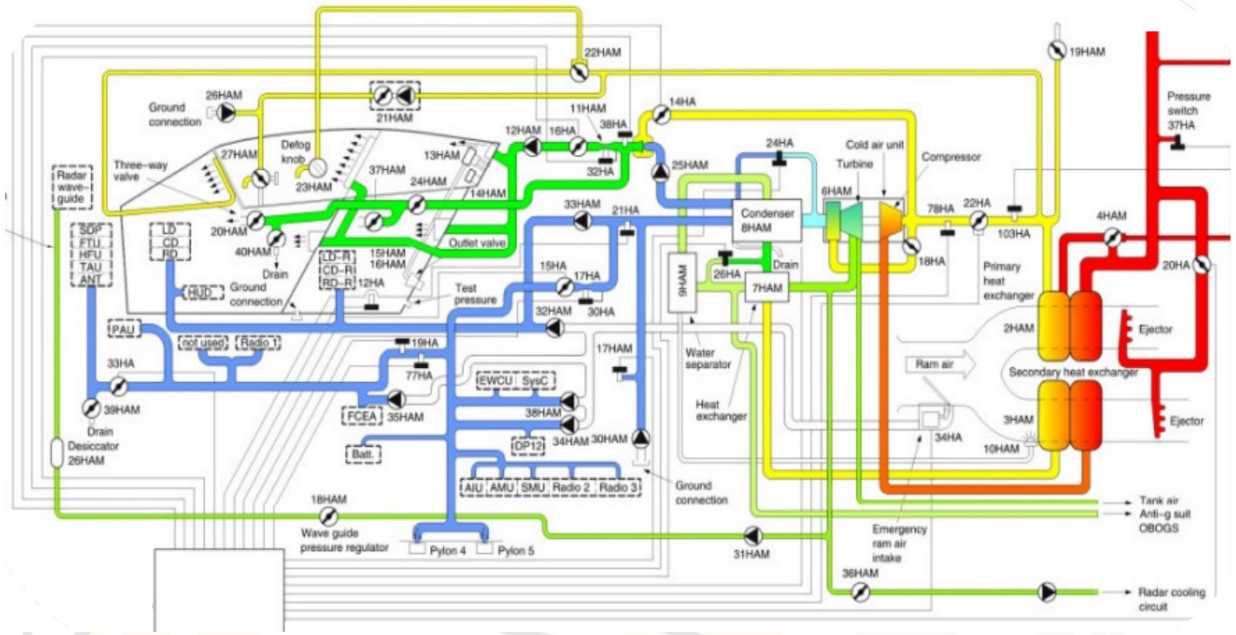
- Maintained and used as a Digital Shadow or Twin continuously and pro-actively alongside its physical counterpart.

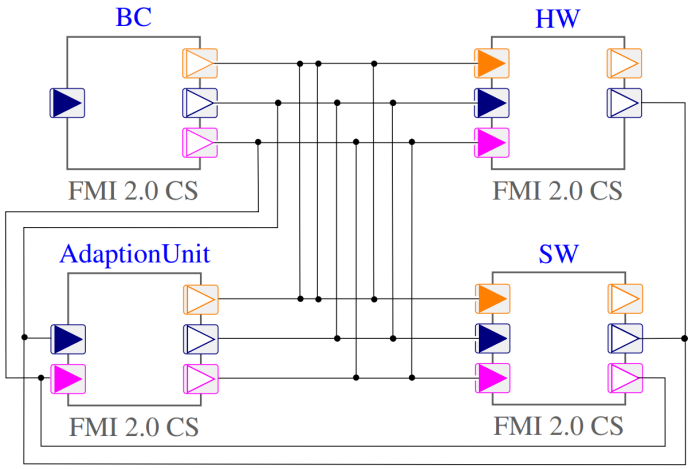


Example

Environmental Control System (example)

1 Architecture model

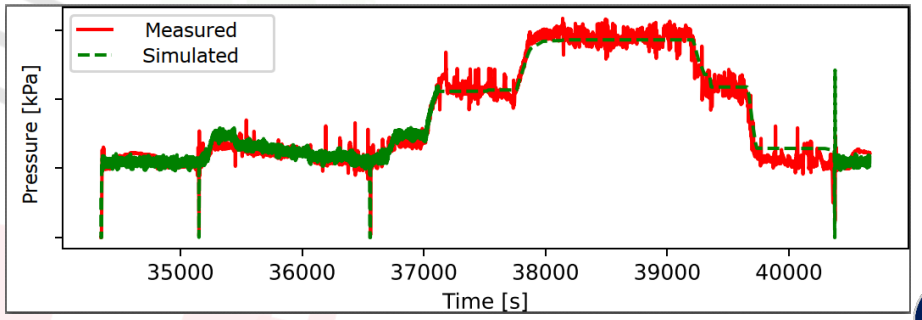




3 Analysis Architecture model

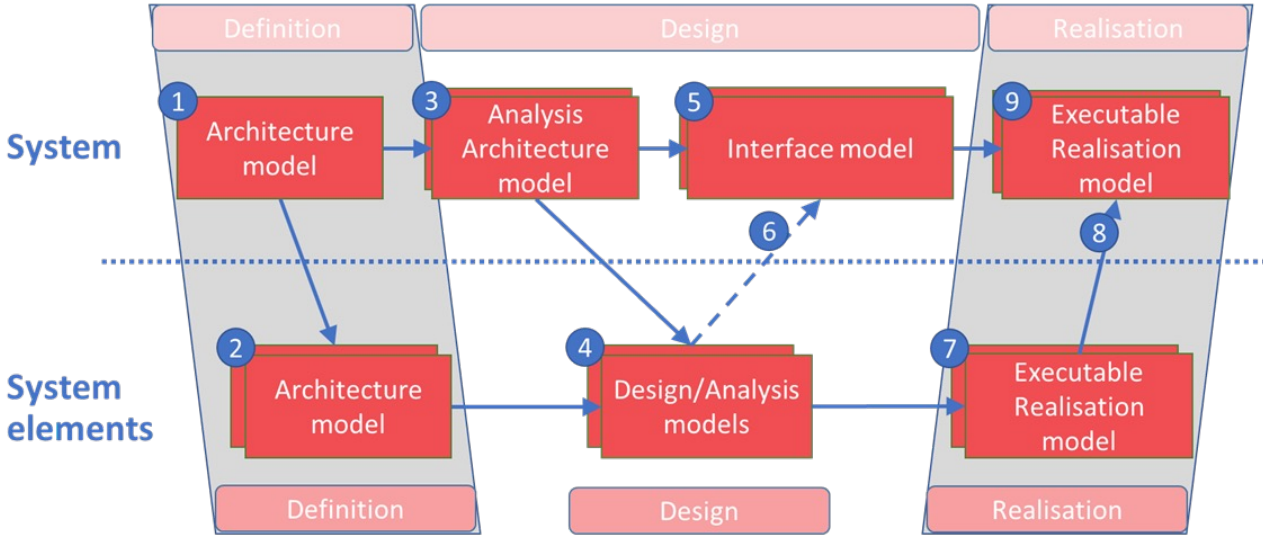
4 Analysis models

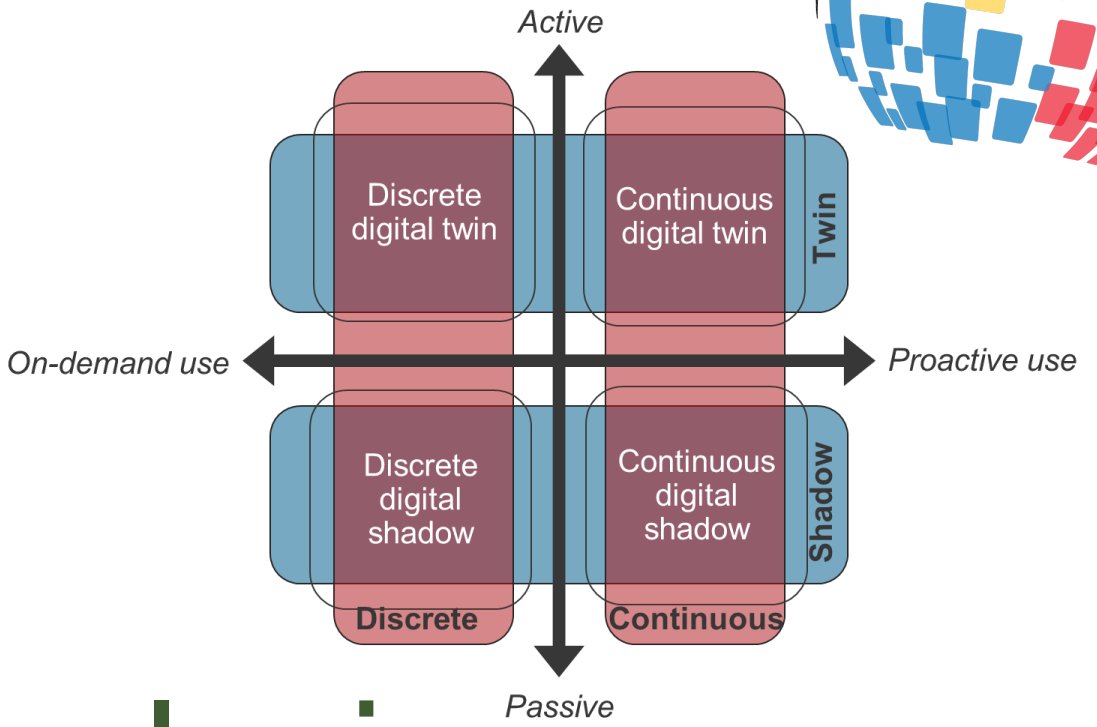
9 Executable Realisation model



Digital Shadow

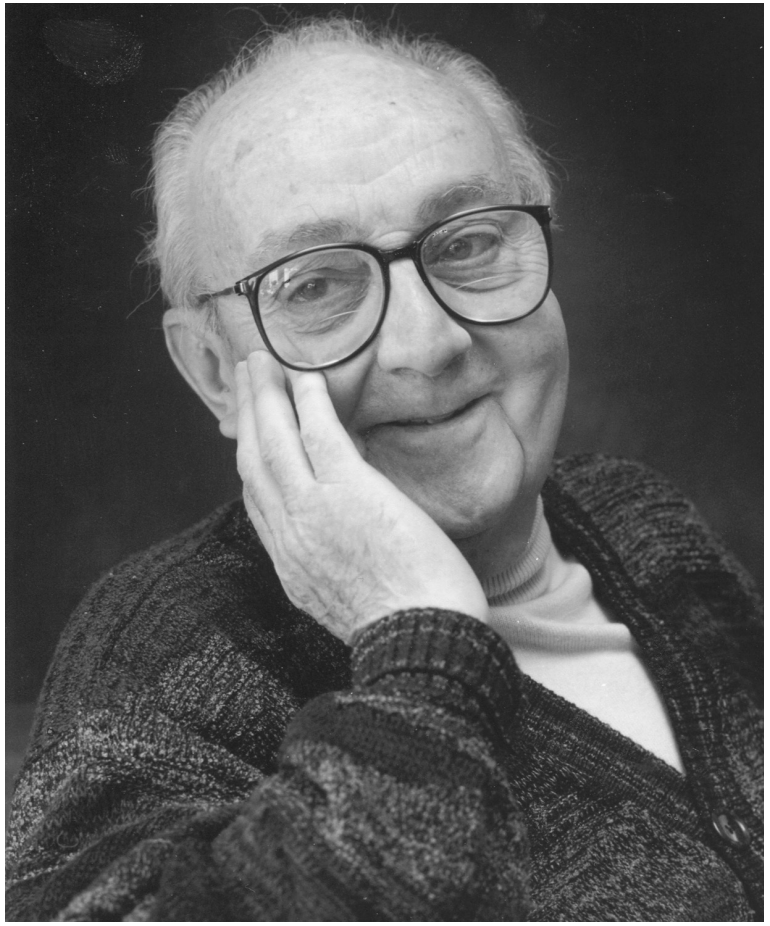
Digital Twin





Discussion & Conclusions

Excuse me Sir, WHICH model?



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Digital Transformation is Transforming

- Digital transformation terminology is in flux → overlap and ambiguity
  - Digital system model, digital twin, digital shadow, digital ecosystem, digital thread …
  - Significant concepts that are transforming development …
    - … if only we could agree which terms relate to which concepts.
- An example: differentiating Digital Twin and Digital Shadow
  - Does such model behave as a control component of the system …
  - … i.e. exhibit behavior not in the real system
- Context: Rapidly evolving technology for integrated model-based methods
  - Developing best practices for graph/ontology
- Numerous forums proposing terminology (INCOSE, AIAA, OMG, …)
  - Full alignment across industries and domains will take time
- Meanwhile, industry interaction requires a basis for contracts and collaboration
  - “Fit for purpose” depends on understanding what is requested and delivered.
  - Success depends on clarity of capability and expected use

DTx capabilities – examples

- **Fidelity of representation:**
  - relevant to the domain perspectives
- **Integration:**
  - engineering and business domains, static or dynamic
- **Relationships to real systems:**
  - unrealized or realized “real” systems
  - information flow between the “real” thing to the model
- **How are the models to be used:**
  - specification, description, prediction
  - “systems of record”, need for accreditation
- **Model connectivity:**
  - Coordinate and align diverse model domains
  - Connect models to “real system” information sources
  - Show compliance across domains
- **Intended application characteristics:**
  - Executability - continuous and on-demand;
  - Track situational awareness -- course of action (e.g., maintenance actions);
  - Predict conditions to proactively recommend or control behavior
  - Analyze performance and recommend controls to optimize operations
- **Relationship to lifecycle:**
  - As-desired, -specified, -designed, -verified, -produced, -maintained
- **Development infrastructure and business model:**
  - Joint or shared environments - enable model exchange,
  - Diverse domain tools, and corresponding information structure.
  - Scalable infrastructure: capacity & responsiveness, change management, information access; long-term archive and retrieval
- **Model development plans:**
  - Coherent Digital Engineering and related development plans
  - Configuration management

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Summary

- Taxonomy
  - Covering Definition, Design and Realisation
  - Extension of Digital Twin and Shadow terminology
  - An extension of the previously published model framework
- Agreement on nomenclature simplifies discussions related to model properties, such as
  - Credibility
  - Model fidelity

NASA 2009. Standard for Models and Simulations: Credibility Assessment Scale, NASA-STD-7009, NASA Technical Standard System, published online: https://standards.nasa.gov/standard/NASA/NASA-STD-7009, accessed 2023-11-27

Future work

- Need to establish a vocabulary for different model types
- Potentially in the form of a concept model
  - Agreement on concepts but allowing diversity of terms
- An activity for INCOSE?

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