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Understanding Modeling and Simulation (M&S) Workflows for Digital Engineering Transformation

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Session Agenda

- Session Objectives
- Digital Engineering with Modeling & Simulation (M&S)
- Background & Approach
- Representing M&S Workflow with Model-Based Systems Engineering (MBSE)
- Identifying Opportunities for M&S Workflow Improvement
- Some Additional Challenges
- Lessons Learned
- Looking Ahead

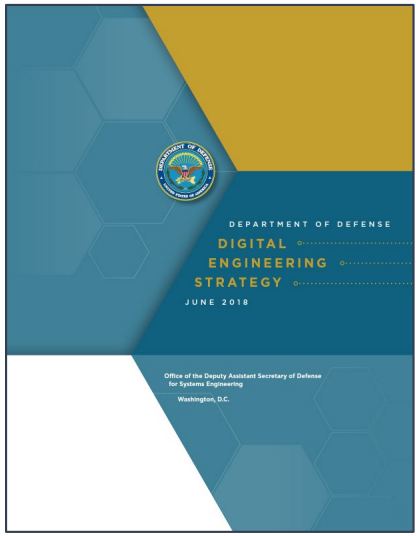
Session Objectives

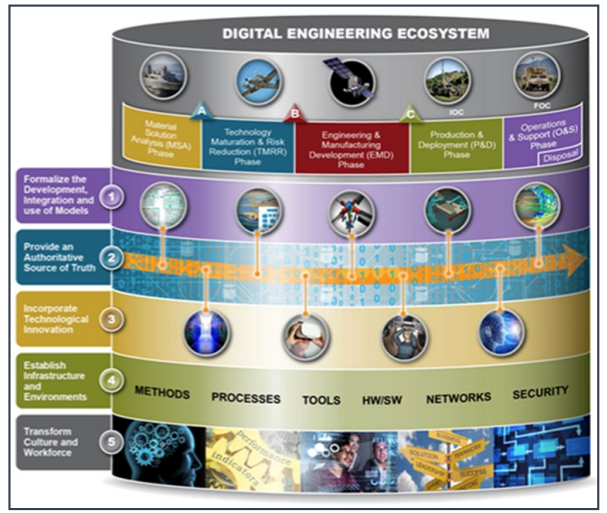
- In this session, we will learn a little bit about:
  - An approach for architecting and understanding the interconnections between simulation models
  - Some MBSE modeling patterns to enable architecting of simulation models
  - Some tools within the Cameo software to query the simulation model architecture
  - Some additional challenges to architecting simulation model workflows

- We hope that you take away the following:
  - Architecting the simulation model enterprise can help to identify opportunities for workflow improvements
  - Using an MBSE approach to simulation model information can capture the details that enable discussions on simulation assumptions and reuse
  - Capturing the right information in an enterprise architecture enables the right discussions with the stakeholders

Digital Engineering with Modeling & Simulation (M&S)

- The use of models is core to digital engineering as described in the United States Department of Defense Digital Engineering Strategy in 2018:
  - Digital engineering is the *"**integrated digital approach** that **uses authoritative sources of systems' data** and models as a continuum across disciplines **to support lifecycle activities from concept through disposal**."* (DoD Digital Engineering Strategy, 2018)
- For some organizations, physics-based M&S is already core to the organization's enterprise
  - How can we improve an organization's M&S execution using digital engineering principles?
- A few principles that come to mind from the digital engineering definition alone:
  - Better integration of models
    - ("***integrated digital approach*** ")
  - Better alignment of models to the authoritative sources of truth
    - ("***uses authoritative sources of systems' data***")
  - Better usage of models to support of the engineering lifecycle
    - ("***to support lifecycle activities from concept through disposal***")





Background & Approach

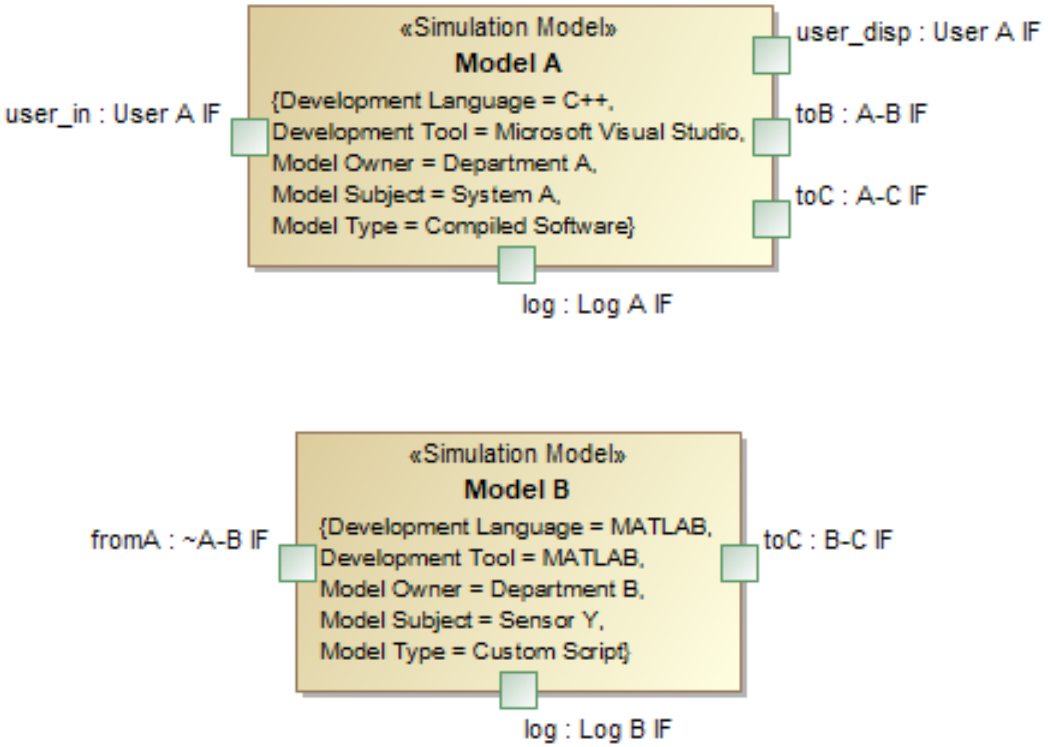
- A department within Johns Hopkins University Applied Physics Laboratory (JHUAPL) wanted to better understand the enterprise interdependencies between physics-based M&S
- We decided to capture the information using a model-based systems engineering (MBSE) approach
  - We captured the information using Dassault Systemes Cameo Systems Modeler 2022x in the SysML 1.7 language
  - We customized the modeling language (metamodel and profile) to better articulate the modeling concepts (e.g., <<Simulation Model>>, <<Analysis Effort>>, <<Program>>, etc.)
- We focused primarily on understanding the interconnections between simulation models within workflows
  - Addressing "Better integration of models"
  - We lightly explored additional relationships:
    - Analysis workflows to programs – "Better usage of models to support of the engineering lifecycle"
    - Simulation models to the system design – "Better alignment of models to the authoritative sources of truth"
- In this session, we will discuss the modeling patterns and some of the observations
  - All examples shown are notional for distribution (e.g., "Model A", "Workflow 1", etc.)

Representing M&S Workflow with MBSE

Defining Simulation Models

- Simulation models are defined as a custom SysML definition elements (<<Simulation Model>>)
  - Modified extension of a SysML block
- Simulation models have the following attributes:
  - Development Language – Programming languages the model is coded in
  - Development Tool – The development tools required to develop the model
  - Model Owner – Organization or department that has ownership over the model
  - Model Subject – The central topic that the model represents
  - Model Type – Enumerated list of additional types for querying later (e.g., Compiled Software vs Custom Script)
- Interfaces on a simulation model are defined by SysML proxy ports typed by interface blocks

Defining Simulation Models Example:
Model A & Model B Definitions

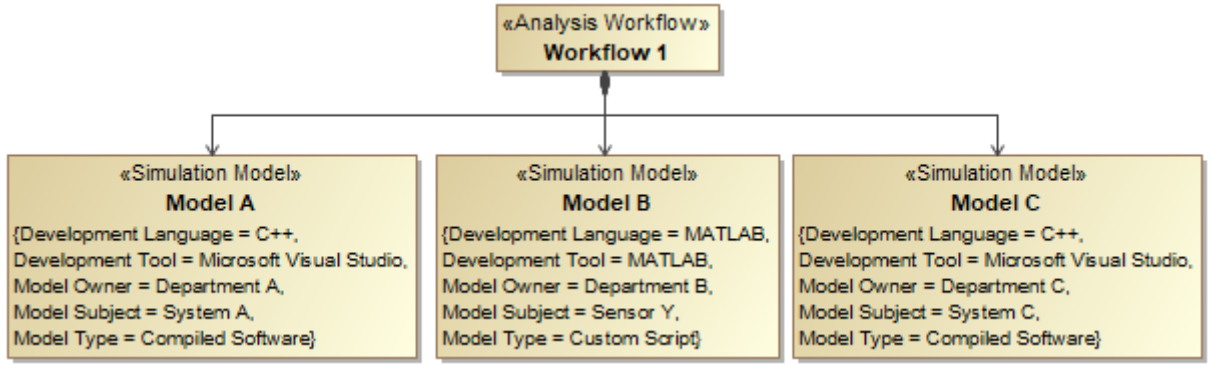


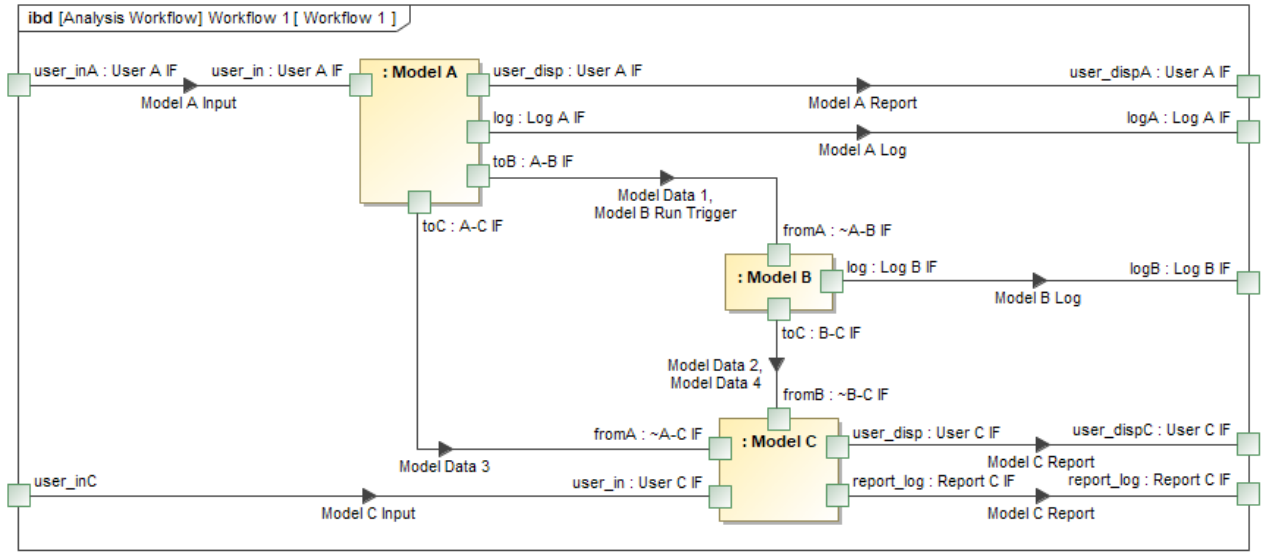
Representing M&S Workflow with MBSE

Defining an Analysis Workflow

- Analysis workflows are defined as a custom SysML definition elements (<<Analysis Workflow>>)
- Analysis workflows are composed of simulation models as parts
- Analysis workflows are expanded upon in a SysML internal block definition diagram to define the interconnections between model interfaces
- Connectors and item flows define the interface flow between simulation models within the workflow

Defining Analysis Workflows Example:
Workflow 1 Definition and Interfaces



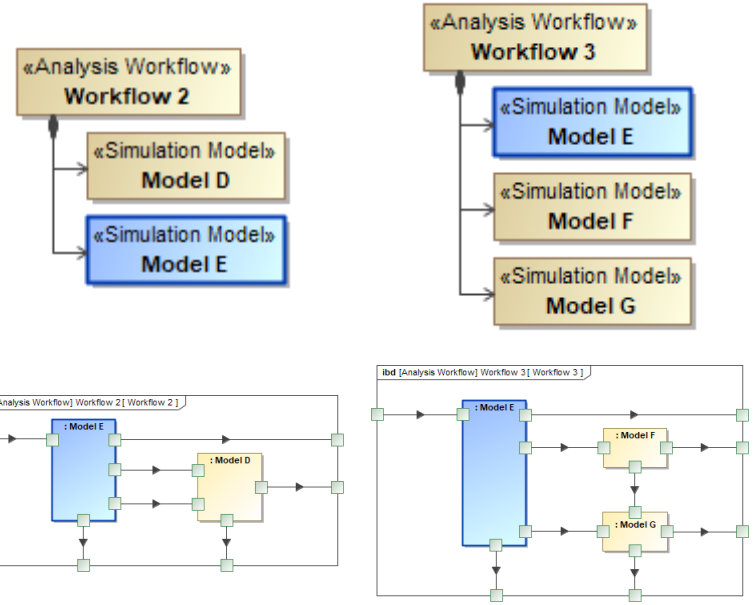


Representing M&S Workflow with MBSE

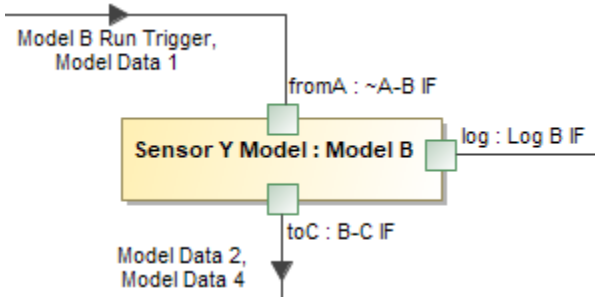
Defining an Analysis Workflow (Continued)

- This modeling pattern enables the capture of a few different forms of reuse
  - Reuse of models across multiple workflows
  - Reuse of an interface with different connections (e.g., common file input format)
- Additional information can be applied to the workflow as needed
  - On interfaces (e.g., file interface vs. data connection)
  - On connectors (e.g., timing information)
  - On item flows (e.g., information sensitivity)
  - On part properties / model usage (e.g., Model B in the role of Sensor Y Model)
- The additional workflow information can be queried later

Model Reuse Example:
Model E Reused in Workflow 2 & Workflow 3



Model Usage Role Example:
Model B in the Role of Sensor Y Model

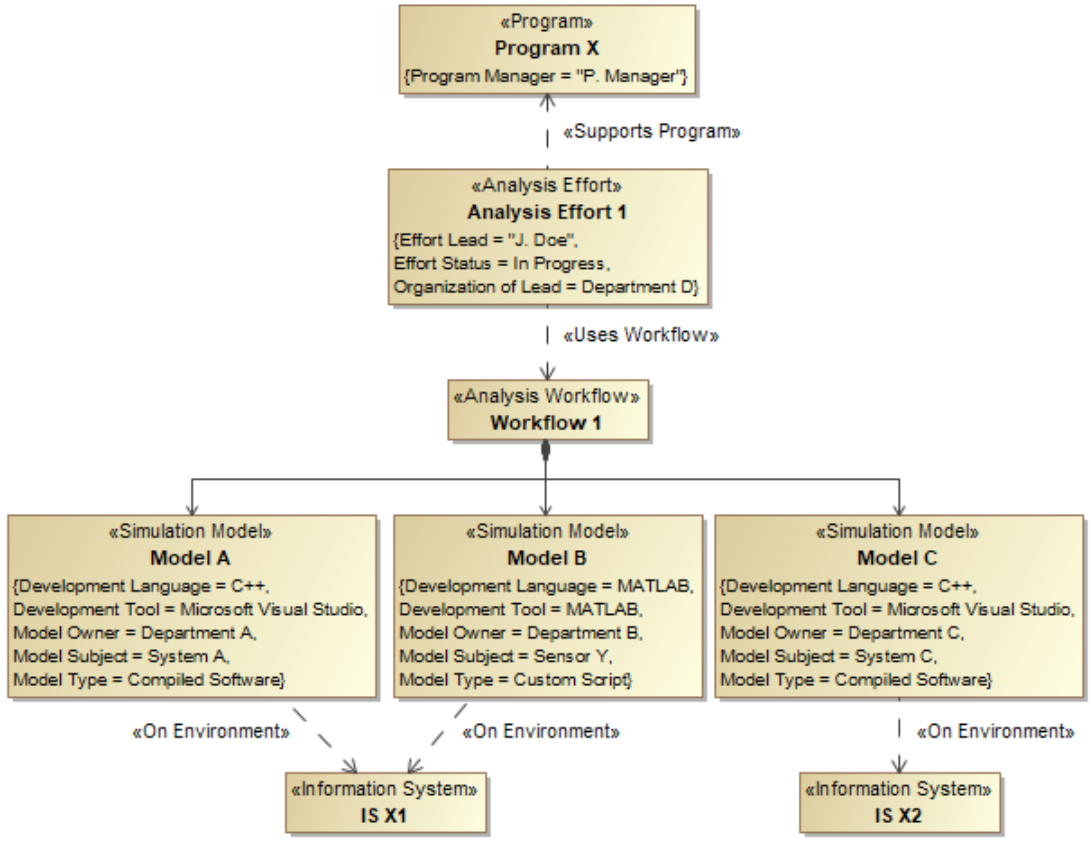


Representing M&S Workflow with MBSE

Relationships to Additional Elements

- Additional concepts are also defined as custom SysML definition elements:
  - Analysis efforts (<<Analysis Effort>>) – Defines an analysis task
  - Programs (<<Program>>) – Defines the program funding the analysis task
  - Information system (<<Information System>>) – Defines the information system that hosts the simulation model
- These concepts can have other additional information:
  - On analysis efforts (e.g., task lead, staffing information)
  - On programs (e.g., program manager, program state)
  - On information systems (e.g., hosting information)
- These concepts are related to the workflow using a custom dependency relation:
  - Analysis Efforts -> Analysis Workflows: <<Uses Workflow>>
  - Analysis Efforts -> Programs: <<Supports Program>>
  - Simulation Models -> Information Systems: <<On Environment>>
- These modeling patterns can be adjusted depending on the desired uses from the architecture stakeholders

Additional Concepts Example:
Modeling Pattern around Workflow 1

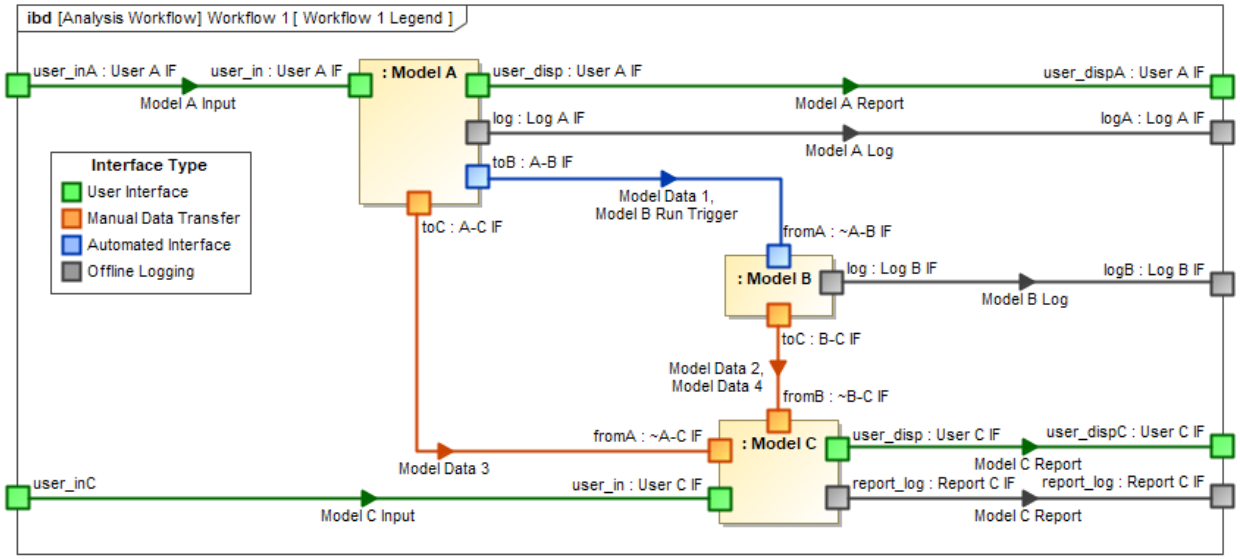


Identifying Opportunities for M&S Workflow Improvement

Filtering of Key Workflow Features

- The architecture content can be filtered to highlight specific workflow features
  - In Cameo, legend coloring and table diagram filtering can be used to focus on a specific feature
- Some examples of identifying potential workflow improvements from filtering:
  - Identifying manual model data movement that can be improved through automation
  - Identifying model data movement that have unique constraints that may need revisiting (e.g., information crossing different information systems)
  - Identifying opportunities for defining a common model interface and enabling reuse

Workflow Highlighting Example:
Workflow 1 Interfaces Highlighted



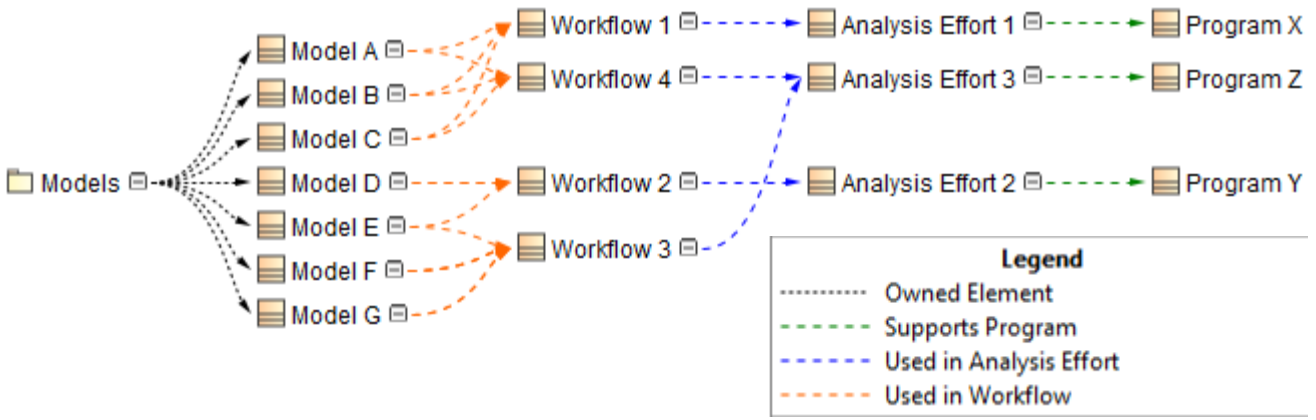
Identifying Opportunities for M&S Workflow Improvement

End-to-End Traceability

- The architecture content also lays out a traceability pattern that can be interrogated
  - In Cameo, relation maps and table diagram custom columns can be used to highlight end-to-end traceability

- Some examples of identifying potential workflow improvements from end-to-end traceability:
  - Identifying which programs are potentially affected by updates to a simulation model
  - Identifying which analysis efforts are potentially affected by downtime to an information system

End-to-End Traceability Example:
Models to Programs (Relation Map)



End-to-End Traceability Example:
Models to Programs (Detailed Table)

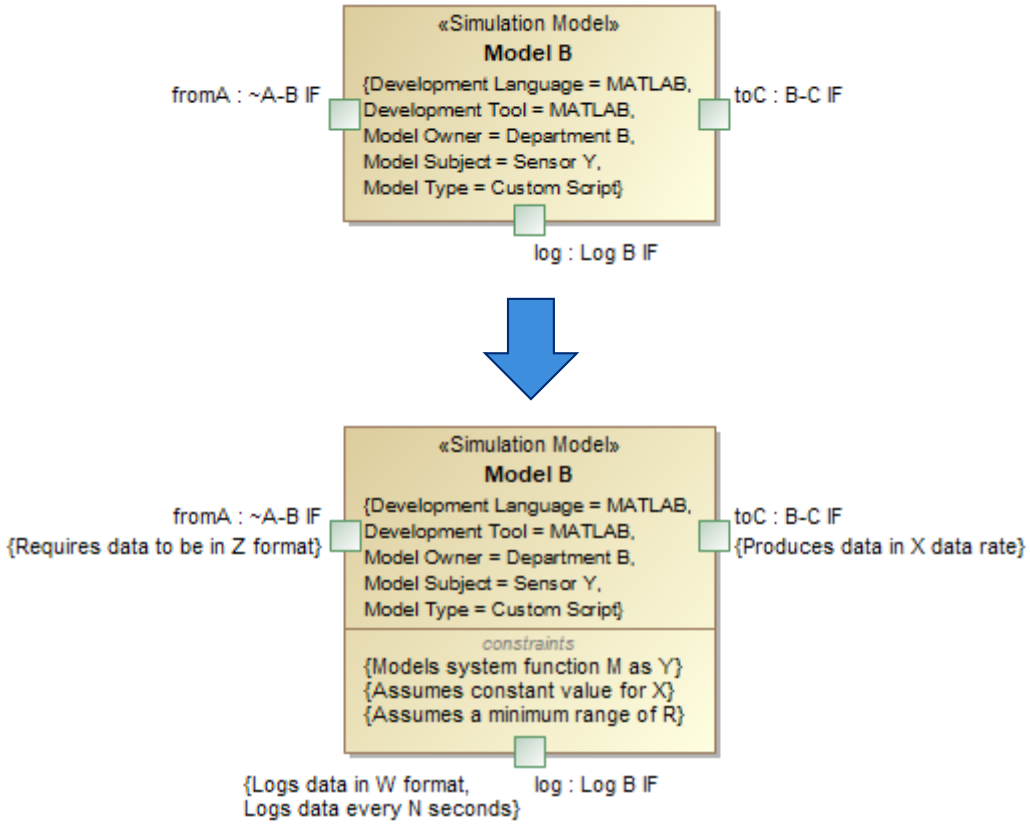
#	Name	Model Subject	Model Type	Development Language	Development Tool	Model Owner	Used in Workflow	Used in Analysis Effort	Supports Program
1	Model A	System A	Compiled Software	C++	Microsoft Visual Studio	Department A	Workflow 1 Workflow 4	Analysis Effort 1 Analysis Effort 3	Program X Program Z
2	Model B	Sensor Y	Custom Script	MATLAB	MATLAB	Department B	Workflow 1 Workflow 4	Analysis Effort 1 Analysis Effort 3	Program X Program Z
3	Model C	System C	Compiled Software	C++	Microsoft Visual Studio	Department C	Workflow 1 Workflow 4	Analysis Effort 1 Analysis Effort 3	Program X Program Z
4	Model D	System D	Compiled Software	Java	Eclipse	Department C	Workflow 2	Analysis Effort 2	Program Y
5	Model E	Sensor X	Compiled Software	C++	Microsoft Visual Studio	Department B	Workflow 2 Workflow 3	Analysis Effort 2 Analysis Effort 3	Program Y Program Z
6	Model F	Sensor X	Custom Script	MATLAB	MATLAB	Department B	Workflow 3	Analysis Effort 3	Program Z

Some Additional Challenges

Reuse of Models and Capturing Model Assumptions

- One of the core concepts of system architecting is element reuse
- Simulation models are difficult to define to enable reuse
  - Our analysts kept pushing back on reusing a simulation model between different workflows due to some assumption on the simulation model
- We realized we can capture simulation model assumptions and use the descriptive detail of system architecting to be more accurate in the assumption
  - SysML constraint elements can be used at various different levels in the work flow to capture the model assumptions and enable discussions on reuse
    - On simulation model block – Assumption that applies to the simulation model in all instances
    - On part property / model usage – Assumption that applies to the simulation model only when used a specific analysis workflow
    - On interfaces / ports – Assumption that applies only to this specific interface on the simulation model
    - On connectors – Assumption that applies to the connection between the simulation models
    - On analysis workflow block – Assumption that applies to the entire workflow

Capturing Model Assumptions Example:
Model B with Constraints



Some Additional Challenges

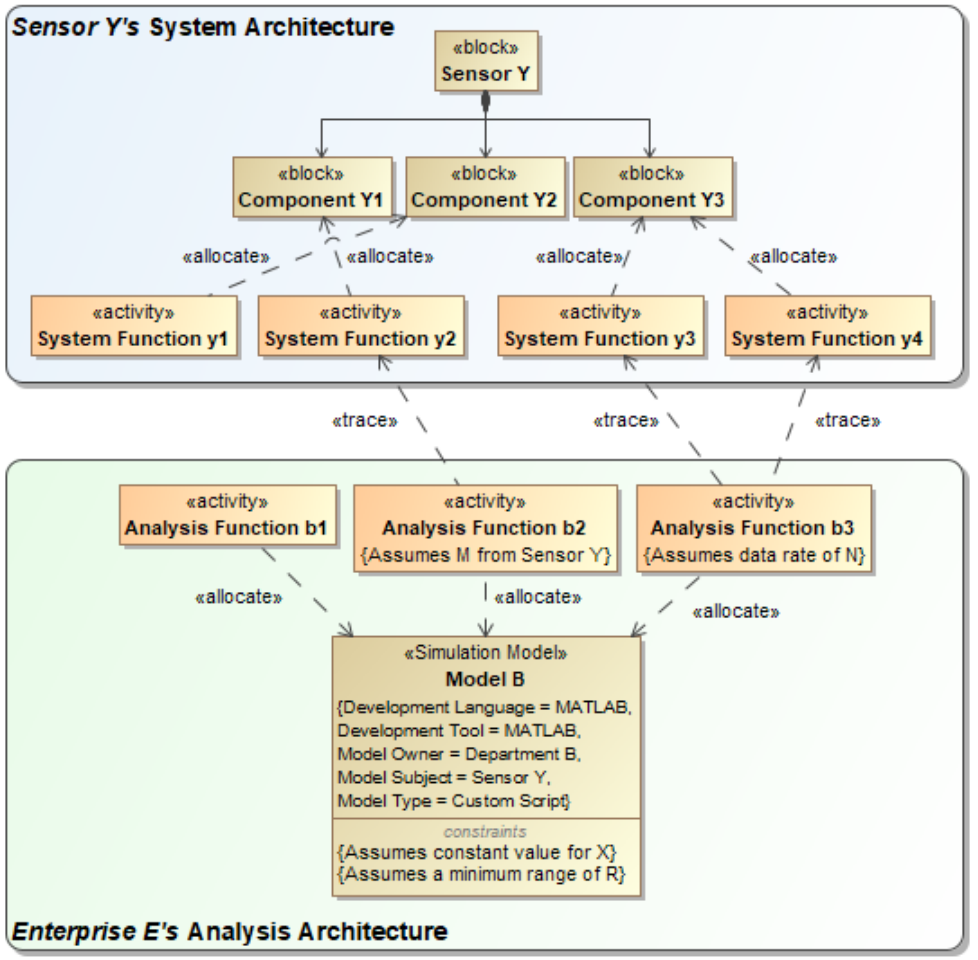
Alignment with the System Architecture

- There can be additional insight if the information in the model workflow architecture is traced to the information in the system architecture

- One approach is defining analysis functions allocated to the simulation model and tracing them to the allocated system functions in the system architecture
  - The traceability to the system function adds clarity to what the simulation model is capturing beyond a model subject
  - If analysis functions are defined as SysML activities, the analysis functions can be further expressed in a process flow through an activity diagram
  - Assumptions to those analysis functions can be added further define additional simulation model detail

- We are still exploring how this modeling pattern can be structured for our specific needs

Alignment with System Architecture Example:
Model B tracing to Sensor Y's Functions

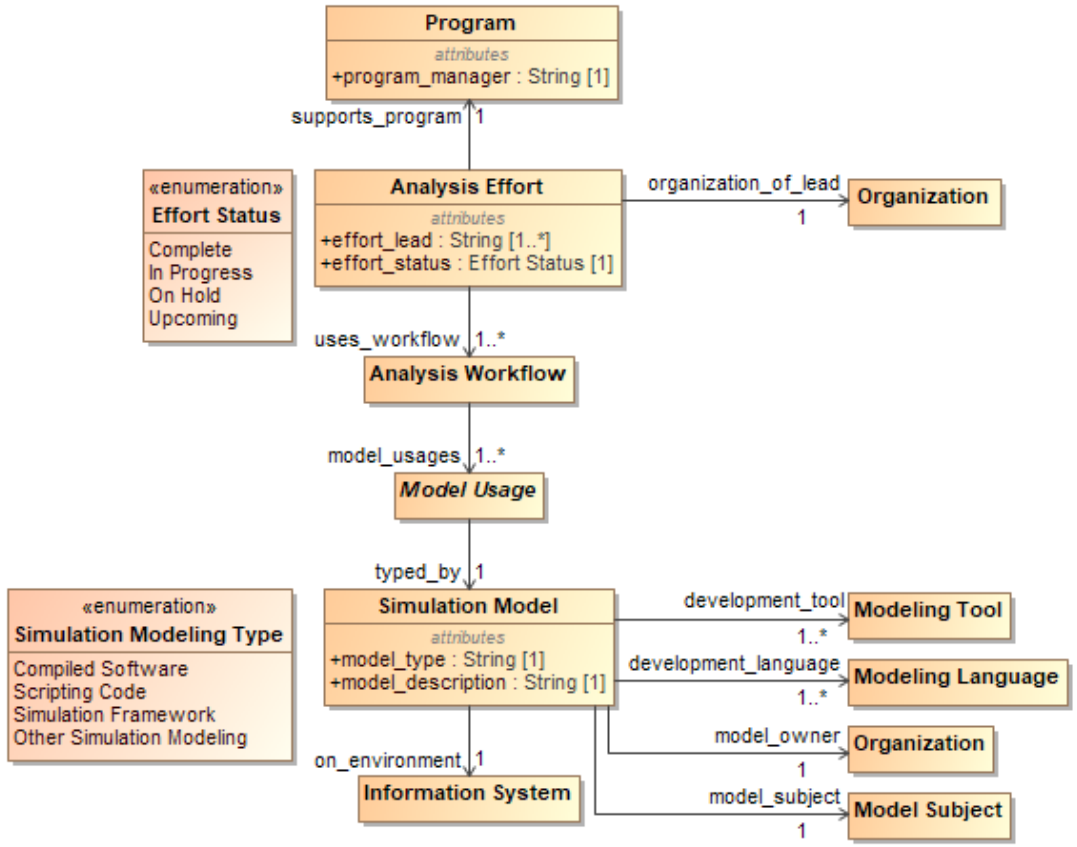


Some Additional Challenges

Capturing Information Updates / Simulation Model Registry & Curation

- Some information in the architecture can have regular updates (e.g., analysis efforts and their task leads)
  - How do we update and maintain this information in the architecture?
- We explored some thoughts around regularly updating information:
  - One idea is to develop a connector to pull the information from the appropriate database into the architecture tool
    - The stakeholders (e.g., task leads) would use their appropriate tool (e.g. task planning software)
    - The architects could use Cameo could pull the information down to develop the workflow architecture
  - Another idea is to develop a purpose-built simulation model registry and curation tool using this workflow architecture as a requirement basis for this capability
    - This architecture already defines a metamodel (entities and relationships) of how to capture the information
    - This purpose-built tool could be easier to use for the stakeholders and can capture the information of an architecture tool to a similar level of detail

Metamodel Example:



Lessons Learned

- Architecting the simulation model enterprise can help to identify opportunities for workflow improvements
  - The architecture can highlight some key attributes and traceability that can drive workflow improvement decisions
- Using an MBSE approach to simulation model information can capture the details that enable discussions on simulation assumptions and reuse
  - The information detail forces discussions with the analysts on why the simulation model is designed a specific way
  - By challenging those assumptions, there is more opportunity to rethink the simulation model's design and consider possibilities for reuse
- Capturing the right information in an enterprise architecture enables the right discussions with the stakeholders
  - The challenge of enterprise modeling is knowing when enough information is captured to enable business decisions
  - Capture and maintain architecture information that answers the questions that the stakeholders regularly request
  - The other detailed information can be captured and maintained in their respective tools (e.g., simulation code in a code repository, task details in a task planning tool, etc.)

Looking Ahead

- Considering transitioning some of these findings into a purpose-built simulation model registry and curation tool

- Exploring more of the interrelationship between the system definition and the simulation model definition
  - This is of special interest to our department as it enables the development of future simulation models along with the development of the system design

- Further discussions with the community on developing better enterprise approaches to modeling & simulation

Questions?

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