



26th annual **INCOSE**
international symposium

Edinburgh, UK
July 18 - 21, 2016

MBSE++ — Foundations for Extended Model-Based Systems Engineering Across System Lifecycle

Authors: Manas Bajaj¹, Dirk Zwemer¹, Rose Yntema¹, Alex Phung¹, Amit Kumar¹, Anshu Dwivedi¹, Manoj Waikar¹

Presenter: Lonnie VanZandt (*Thank you Lonnie!*)

1



intercax

www.intercax.com

Contents

- Introduction
- 6 principles of MBSE++
- Short video illustration
- Summary
- Q & A



INCOSE SE Vision 2025

www.inco



Interconnected

Interdependent

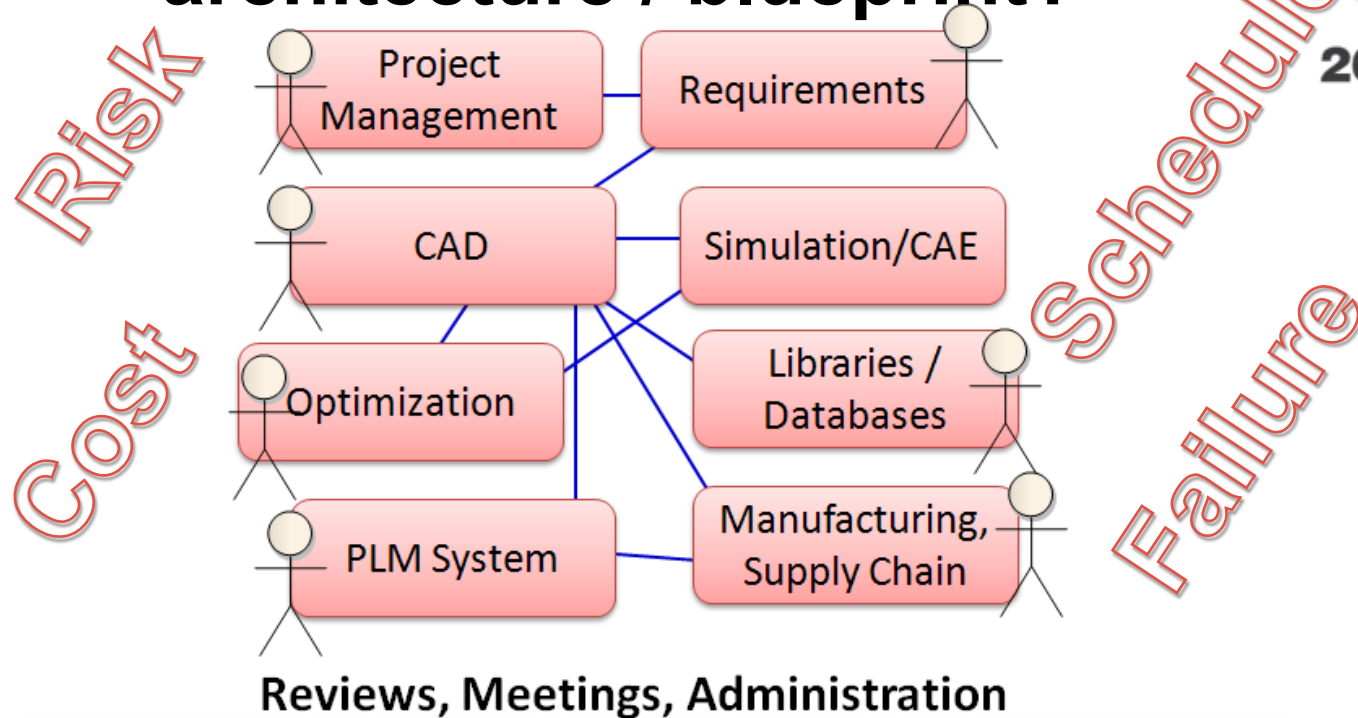
Complex

INCOSE SE Vision 2025

<http://goo.gl/uE5OS9>

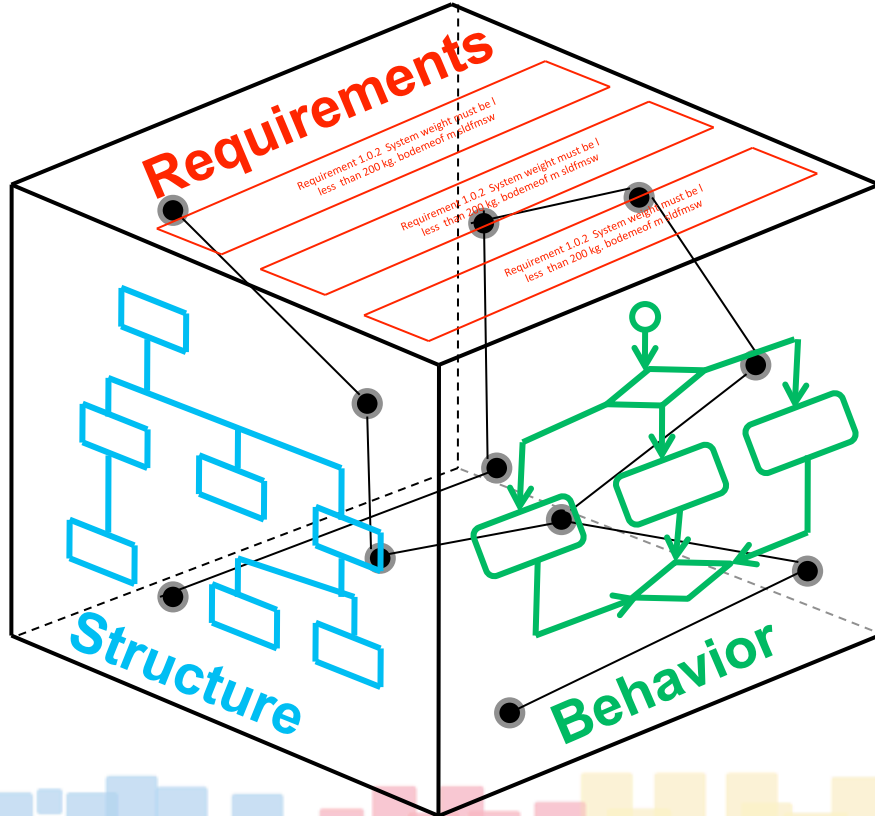
Challenge – Where is the system architecture / blueprint?

Point-to-point ad-hoc
information flows



Use of models in systems engineering IS NOT
model-based systems engineering (MBSE)

Transition from Document-Based to Model-Based Systems Engineering



- MBSE = Unified model of the system versus series of disconnected documents (DBSE)
- System docs and views can be generated from this unified model
- DBSE > MBSE \Leftrightarrow 2D > 3D CAD
- Models in SE \neq MBSE

DBSE > MBSE > MBSE++



- OMG SysML – www.omgsysml.org
 - Widely adopted as a standard for modeling, analyzing, and developing system architecture
- However
 - Most of the detailed engineering carried out in domain-specific tools and repositories, such as in PLM, ALM, Req. Mgt., Databases, Simulation env., Project Mgt., CAD, CAE, and more

What is MBSE++

2012-07-12, 1000h US ET

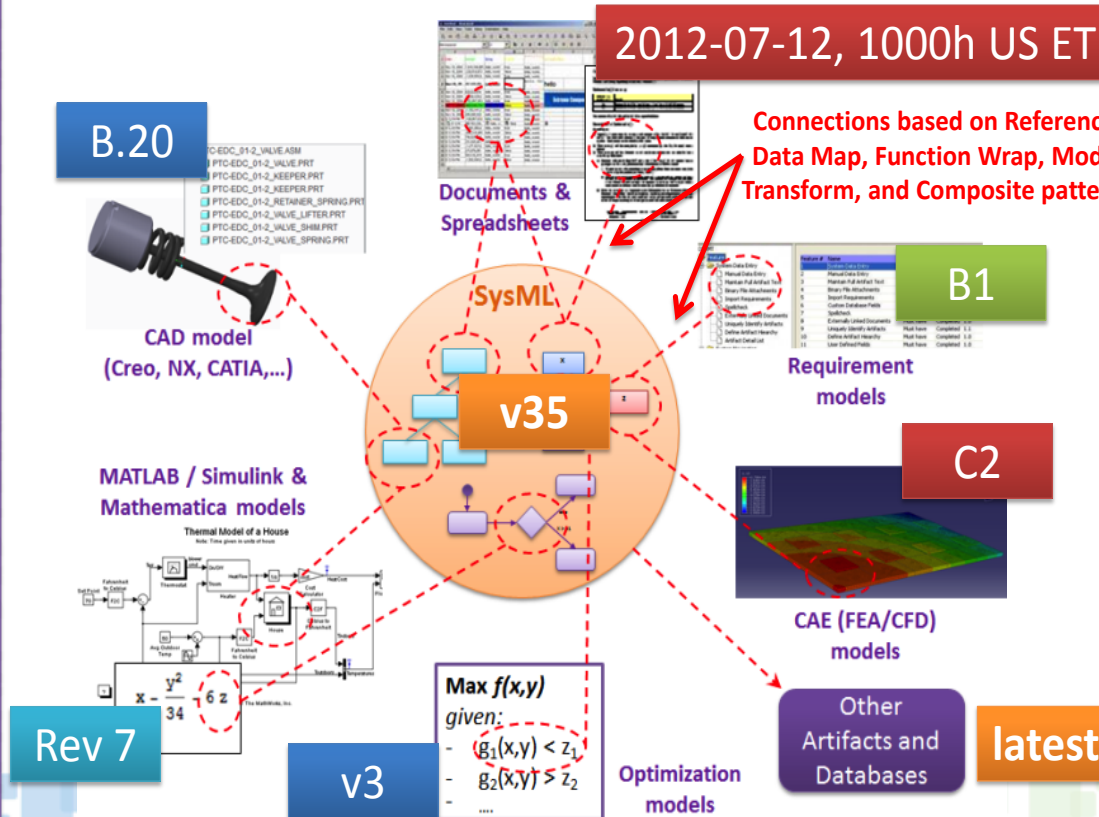
Connections based on Reference,
Data Map, Function Wrap, Model
Transform, and Composite patterns

Connect architecture model
(SysML) with domain-specific
models

Total System Model (TSM) as
a digital blueprint of the system

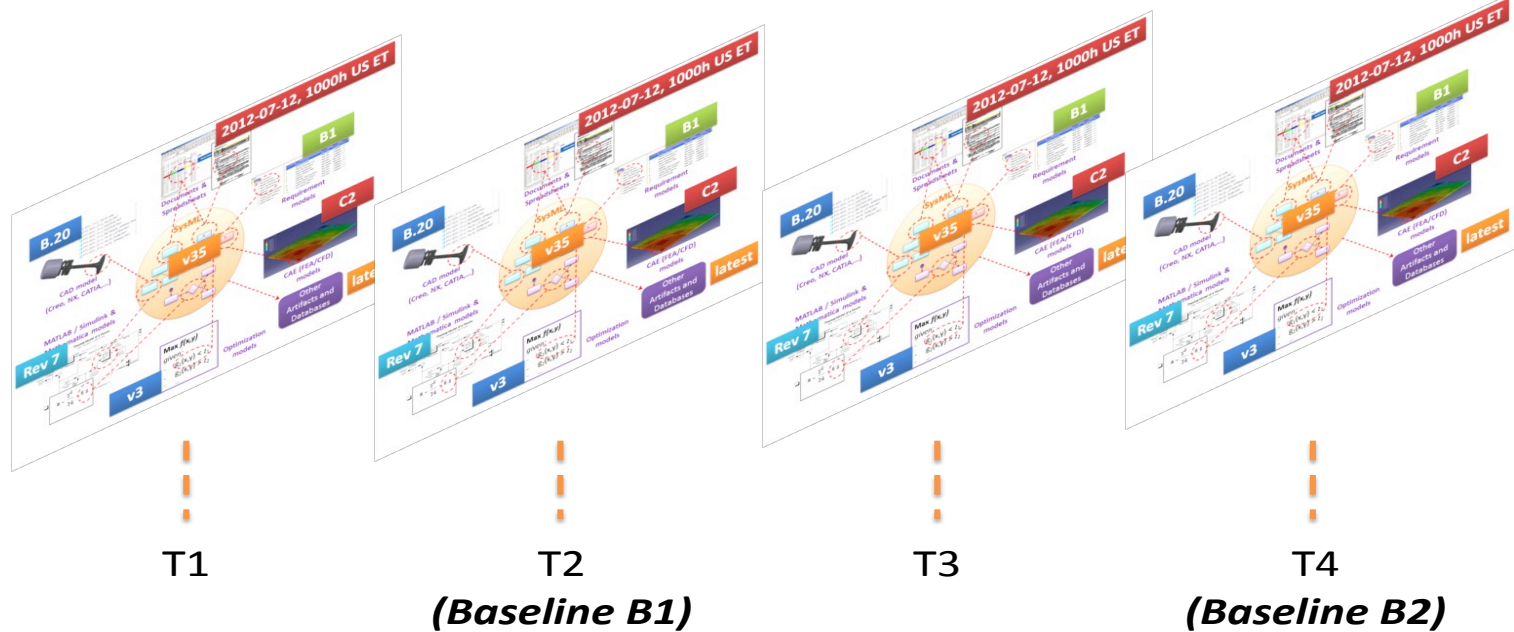
Goal: Seamless traceability
between disciplines across the
system lifecycle

TOTAL SYSTEM MODEL (TSM)

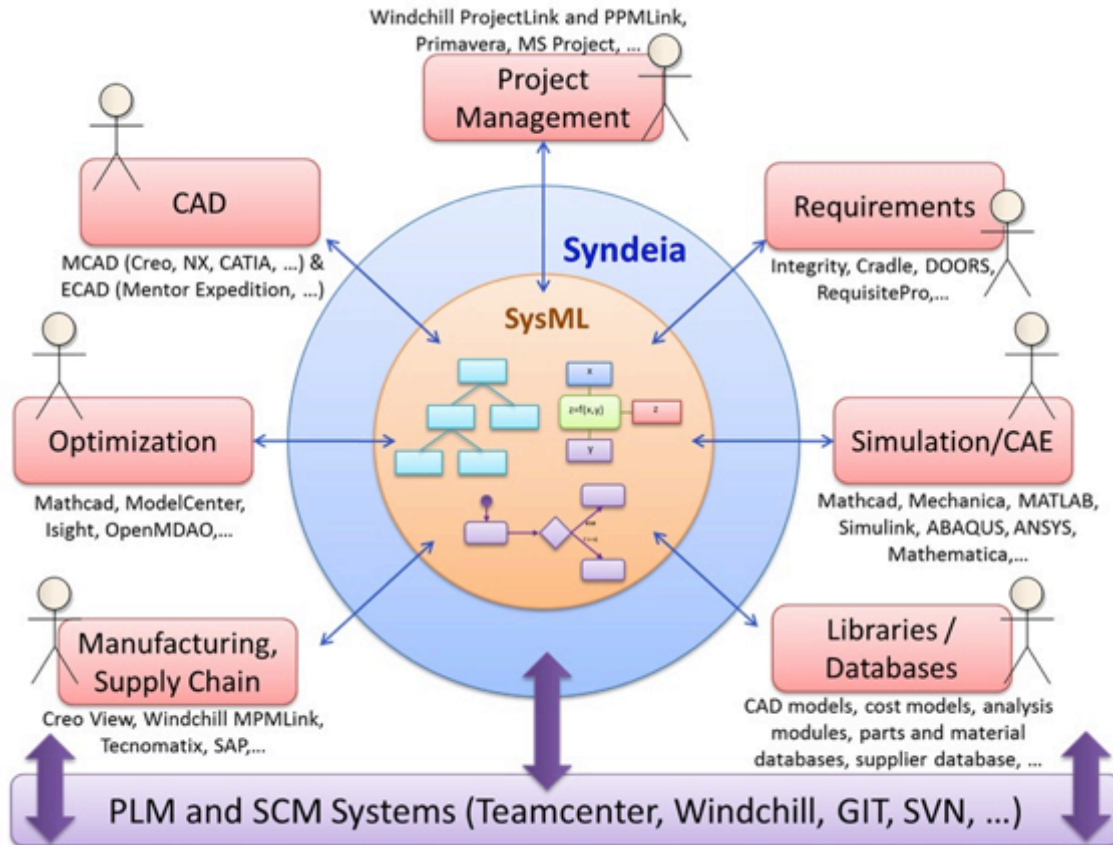


Total System Model (TSM)

TSM evolves as each of the version-managed models evolve



Syndeia = Software Platform for MBSE++



Search, Connect, Access,
Transform, Compare, Sync,
Visualize models in the TSM

We will illustrate 6 principles
of MBSE++ using Syndeia

Syndeia 3.0 released July
2016 – www.syndeia.com

Contents

- Introduction
- 6 principles of MBSE++
- Short video illustration
- Summary
- Q & A



1. Heterogeneous and Decentralized Data



- Wide range of tools used for developing a system
- Total System Model (TSM) contains models spread across multiple version-controlled enterprise repositories and tools, such as:
 - System architecture (SysML - MagicDraw, Rhapsody, Enterprise Architect, Integrity Modeler)
 - Project management (MS Project, JIRA)
 - PLM (Teamcenter, Windchill, Aras)
 - Requirements Management (DOORS, JAMA, Teamcenter, Integrity)
 - ALM (GitHub, Bitbucket, JIRA)
 - Simulation (Mathematica, MATLAB, Simulink, Modelica, FEA/CFD – ANSYS, ABAQUS)
 - Databases (MySQL, Oracle, SQL Server, MongoDB, Neo4j)

1. Heterogeneous and Decentralized Data



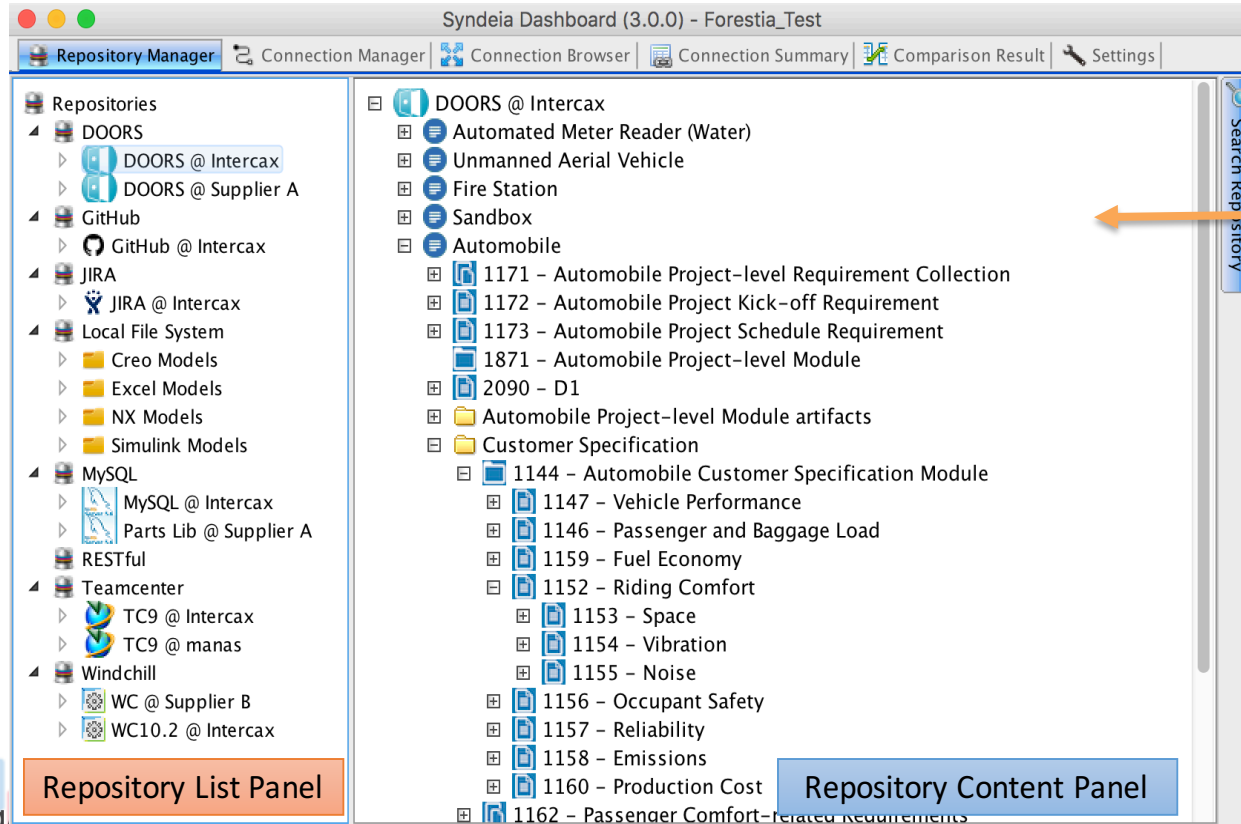
- Wide range of:
 - Modeling languages (SysML, Modelica, Simscape, XML, EXPRESS,...)
 - Data formats (XML, JSON,...)
 - APIs
 - Standards (ISO STEP, JDBC, FMI, OSLC,...)
 - Communication modes (Web services – REST, SOAP, File exchange,...)

1. Heterogeneous and Decentralized Data

(Screenshots from Syndeia -1/2)

Access multiple enterprise repositories

(PLM, ALM, Databases, Req. Mgt, Project Mgt, Drives)



Syndeia Dashboard (3.0.0) - Forestia_Test

Repository Manager | Connection Manager | Connection Browser | Connection Summary | Comparison Result | Settings

Repository List Panel

- Repositories
 - DOORS
 - DOORS @ IntercaX
 - DOORS @ Supplier A
 - GitHub
 - GitHub @ IntercaX
 - JIRA
 - JIRA @ IntercaX
 - Local File System
 - Creo Models
 - Excel Models
 - NX Models
 - Simulink Models
 - MySQL
 - MySQL @ IntercaX
 - Parts Lib @ Supplier A
 - RESTful
 - Teamcenter
 - TC9 @ IntercaX
 - TC9 @ manas
 - Windchill
 - WC @ Supplier B
 - WC10.2 @ IntercaX

Repository Content Panel

DOORS @ IntercaX

- Automated Meter Reader (Water)
- Unmanned Aerial Vehicle
- Fire Station
- Sandbox
- Automobile
 - 1171 - Automobile Project-level Requirement Collection
 - 1172 - Automobile Project Kick-off Requirement
 - 1173 - Automobile Project Schedule Requirement
 - 1871 - Automobile Project-level Module
 - 2090 - D1
 - Automobile Project-level Module artifacts
 - Customer Specification
 - 1144 - Automobile Customer Specification Module
 - 1147 - Vehicle Performance
 - 1146 - Passenger and Baggage Load
 - 1159 - Fuel Economy
 - 1152 - Riding Comfort
 - 1153 - Space
 - 1154 - Vibration
 - 1155 - Noise
 - 1156 - Occupant Safety
 - 1157 - Reliability
 - 1158 - Emissions
 - 1160 - Production Cost
 - 1162 - Passenger Comfort-related Requirements

Browse and search repository contents

1. Heterogeneous and Decentralized Data (Screenshots from Syndeia -2/2)

Syndeia Dashboard (2.0.0) - Unmanned Aerial Vehicle

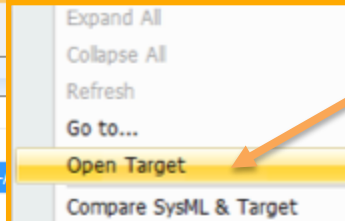
Repository Manager Connection Manager Connection Browser Connection Summary Comparison

Type here to filter connections

Source (SysML Element)	Name	Type	Target
Unmanned Aerial Vehicle			
Aircraft Platform			
Analysis Manager	[Unmanned Aerial Vehicle::...	BLOCK_TC_PART_MODE...	000465/E; 1-
APU	[Unmanned Aerial Vehicle::...	BLOCK_TC_PART_MODE...	000492
Autopilot	[Unmanned Aerial Vehicle::...	BLOCK_TC_PART_MODE...	000566
Battery	[Unmanned Aerial Vehicle::...	BLOCK_TC_PART_MODE...	000467
BlackBox	[Unmanned Aerial Vehicle::...	BLOCK_TC_PART_MODE...	000567
Body	[Unmanned Aerial Vehicle::...	BLOCK_TC_PART_MODE...	002676
Communications Controller	[Unmanned Aerial Vehicle::...	BLOCK_TC_PART_MODE...	000478

[loaded] between artifacts {[Unmanned Aerial Vehicle::Communications Interface]} and {[000493/A;1-Comm... successfully added to connection manager

Ready



View models in
native repositories
from the TSM

SIEMENS My Teamcenter

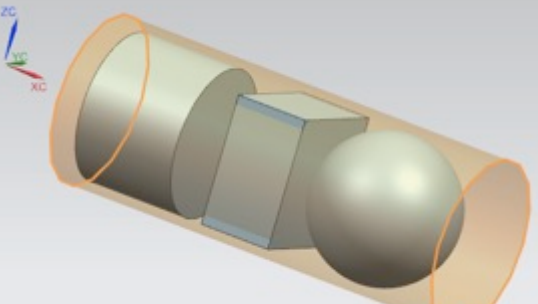
Overview Related Datasets Impact Analysis

Available Revisions Viewer Details

000465/E; 1-Aircraft Platform Owner: Manas Bajaj (manas)

Last Modified Date: 23-Apr-2014 15:21 Release Status:

Type: ItemRevision



2. Capturing & Maintaining the High-level System Architecture



- Challenges

- High-level system definition to coordinate and orchestrate disciplines – project management, mechanical/electrical design, simulation, software, part suppliers, and other vendors
- Domain-specific models / specifications should be derived from system architecture, or vice versa, and connected
- System architecture needed for verifying system-level requirements, assessing emerging system behavior, and as the entry point for system engineers

2. Capturing & Maintaining the High-level System Architecture



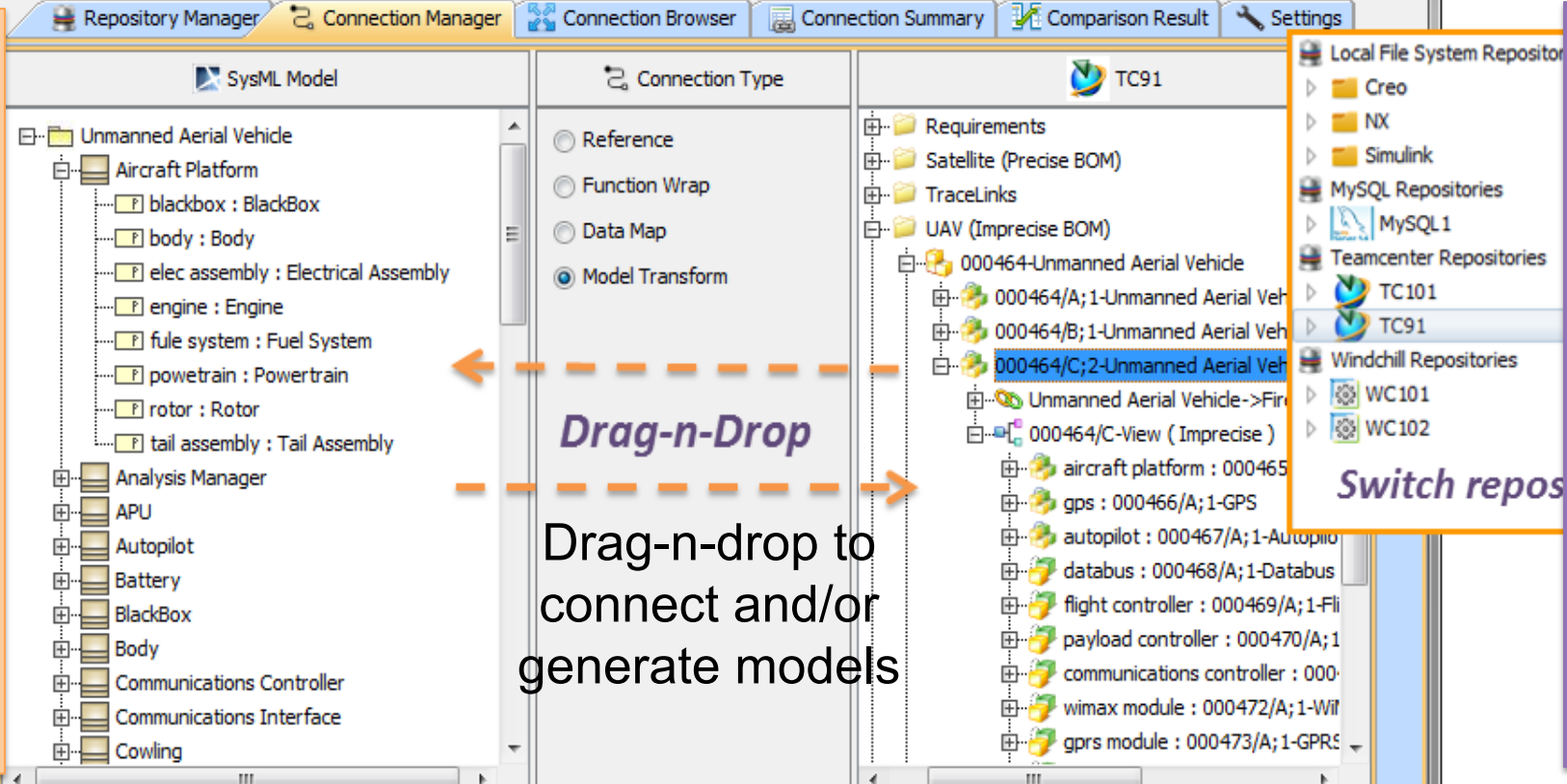
- Use Cases (some examples)
 - Compose system architecture (SysML) from libraries of parts (PLM), software (ALM), data (DB), and keep all connected
 - Seed PLM BoM & simulation models from system architecture (structure and function), and keep all connected
 - System mass requirement verification needs part/sub-system mass information originating from 3D CAD

2. Capturing & Maintaining the High-level System Architecture

(Screenshots from Syndeia 1/2)

System Architecture (SysML)

Domain-specific models



The screenshot displays the Syndeia software interface with three main panes:

- SysML Model:** A hierarchical tree structure under "Unmanned Aerial Vehicle". It includes sub-elements like "Aircraft Platform" (with sub-elements: blackbox : BlackBox, body : Body, elec assembly : Electrical Assembly, engine : Engine, fuel system : Fuel System, powertrain : Powertrain, rotor : Rotor, tail assembly : Tail Assembly), "Analysis Manager", "APU", "Autopilot", "Battery", "BlackBox", "Body", "Communications Controller", "Communications Interface", and "Cowling".
- Connection Type:** A list of connection types with radio buttons: Reference, Function Wrap, Data Map, and Model Transform (which is selected).
- TC91:** A list of repositories and models. It includes "Requirements", "Satellite (Precise BOM)", "TraceLinks", "UAV (Imprecise BOM)", and a list of specific models like "000464-A;1-Unmanned Aerial Veh", "000464/B;1-Unmanned Aerial Veh", "000464/C;2-Unmanned Aerial Veh" (highlighted), "Unmanned Aerial Vehicle->Fire", "000464/C-View (Imprecise)", "aircraft platform : 000465", "gps : 000466/A;1-GPS", "autopilot : 000467/A;1-Autopilo", "databus : 000468/A;1-Databus", "flight controller : 000469/A;1-Fli", "payload controller : 000470/A;1", "communications controller : 000", "wimax module : 000472/A;1-Wil", and "gprs module : 000473/A;1-GPRS".

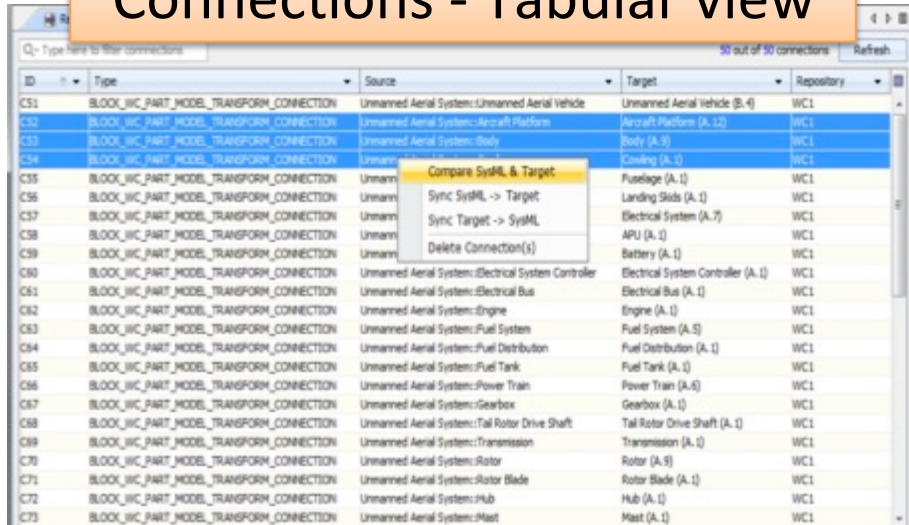
Annotations on the screenshot include:

- A vertical orange bar on the left labeled "System Architecture (SysML)".
- A vertical purple bar on the right labeled "Domain-specific models".
- A dashed orange arrow pointing from the SysML Model pane to the TC91 pane, labeled "Drag-n-Drop".
- Text below the arrow: "Drag-n-drop to connect and/or generate models".
- A callout box on the right titled "Switch repos" showing a list of repositories: Local File System Repository, Creo, NX, Simulink, MySQL Repositories, MySQL 1, Teamcenter Repositories, TC101, TC91, Windchill Repositories, WC101, and WC102.

2. Capturing & Maintaining the High-level System Architecture

(Screenshots from Syndeia – 2/2)

Connections - Tabular view



ID	Type	Source	Target	Repository
C31	BLOCK_WIC_PART_MODEL_TRANSFORM_CONNECTION	Unmanned Aerial System:Unmanned Aerial Vehicle	Unmanned Aerial Vehicle (B-4)	WC1
C32	BLOCK_WIC_PART_MODEL_TRANSFORM_CONNECTION	Unmanned Aerial System:Aircraft Platform	Aircraft Platform (A-12)	WC1
C33	BLOCK_WIC_PART_MODEL_TRANSFORM_CONNECTION	Unmanned Aerial System:Body	Body (A-8)	WC1
C34	BLOCK_WIC_PART_MODEL_TRANSFORM_CONNECTION	Unmanned Aerial System:Wing	Wing (A-2)	WC1
C35	BLOCK_WIC_PART_MODEL_TRANSFORM_CONNECTION	Unmanned Aerial System:Engine	Engine (A-1)	WC1
C36	BLOCK_WIC_PART_MODEL_TRANSFORM_CONNECTION	Unmanned Aerial System:Landing Gear	Landing Gear (A-1)	WC1
C37	BLOCK_WIC_PART_MODEL_TRANSFORM_CONNECTION	Unmanned Aerial System:Electrical System	Electrical System (A-7)	WC1
C38	BLOCK_WIC_PART_MODEL_TRANSFORM_CONNECTION	Unmanned Aerial System:APU	APU (A-1)	WC1
C39	BLOCK_WIC_PART_MODEL_TRANSFORM_CONNECTION	Unmanned Aerial System:Battery	Battery (A-1)	WC1
C40	BLOCK_WIC_PART_MODEL_TRANSFORM_CONNECTION	Unmanned Aerial System:Electrical System Controller	Electrical System Controller (A-1)	WC1
C41	BLOCK_WIC_PART_MODEL_TRANSFORM_CONNECTION	Unmanned Aerial System:Electrical Bus	Electrical Bus (A-1)	WC1
C42	BLOCK_WIC_PART_MODEL_TRANSFORM_CONNECTION	Unmanned Aerial System:Engine	Engine (A-1)	WC1
C43	BLOCK_WIC_PART_MODEL_TRANSFORM_CONNECTION	Unmanned Aerial System:Fuel System	Fuel System (A-5)	WC1
C44	BLOCK_WIC_PART_MODEL_TRANSFORM_CONNECTION	Unmanned Aerial System:Fuel Distribution	Fuel Distribution (A-1)	WC1
C45	BLOCK_WIC_PART_MODEL_TRANSFORM_CONNECTION	Unmanned Aerial System:Fuel Tank	Fuel Tank (A-1)	WC1
C46	BLOCK_WIC_PART_MODEL_TRANSFORM_CONNECTION	Unmanned Aerial System:Power Train	Power Train (A-6)	WC1
C47	BLOCK_WIC_PART_MODEL_TRANSFORM_CONNECTION	Unmanned Aerial System:Gearbox	Gearbox (A-1)	WC1
C48	BLOCK_WIC_PART_MODEL_TRANSFORM_CONNECTION	Unmanned Aerial System:Tail Rotor Drive Shaft	Tail Rotor Drive Shaft (A-1)	WC1
C49	BLOCK_WIC_PART_MODEL_TRANSFORM_CONNECTION	Unmanned Aerial System:Transmission	Transmission (A-1)	WC1
C70	BLOCK_WIC_PART_MODEL_TRANSFORM_CONNECTION	Unmanned Aerial System:Rotor	Rotor (A-8)	WC1
C71	BLOCK_WIC_PART_MODEL_TRANSFORM_CONNECTION	Unmanned Aerial System:Rotor Blade	Rotor Blade (A-1)	WC1
C72	BLOCK_WIC_PART_MODEL_TRANSFORM_CONNECTION	Unmanned Aerial System:Hub	Hub (A-1)	WC1
C73	BLOCK_WIC_PART_MODEL_TRANSFORM_CONNECTION	Unmanned Aerial System:Mast	Mast (A-1)	WC1

Connections – Graphical view



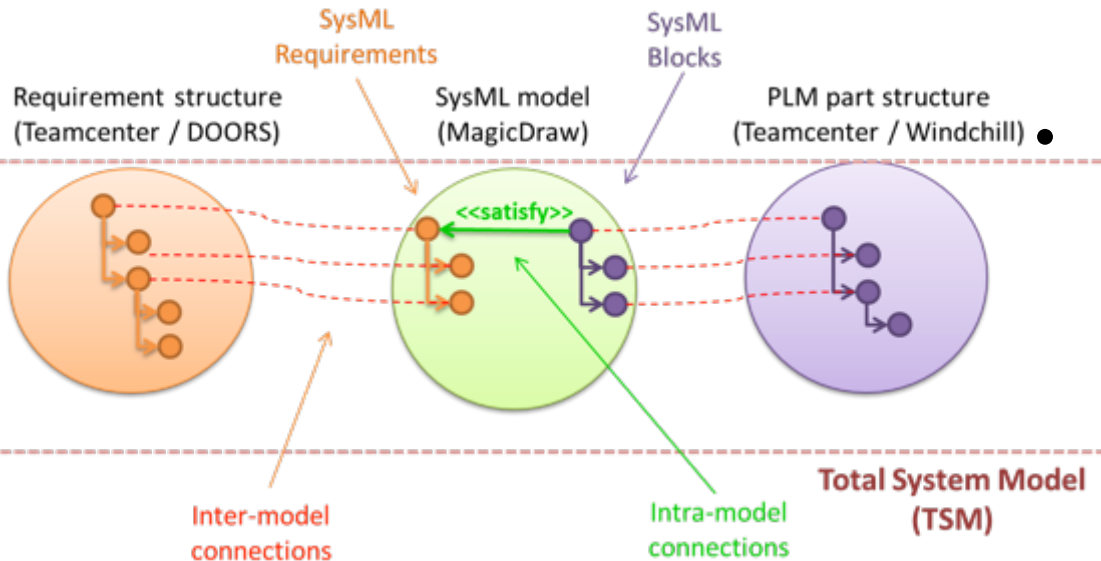
Track all model-based connections between system architecture (SysML) and domain-specific models in PLM, ALM, Databases, Requirements Mgt. and other repositories

3. Spectrum of Model-Based Connections

- Model-based connections are building blocks of interoperability

Types of connections

- **Inter-model** connections are between elements in different models / tools e.g. SysML block – PLM part
- **Intra-model** connections are between elements in same model / tool, e.g. SysML block – SysML requirement



3. Spectrum of Model-Based Connections



- What is the purpose of model-based connections?



Reference Connections

Track/compare/sync versions of connected elements



Data Map Connections

+ Track/compare/sync element attributes



Function Wrap Connections

+ Track/execute connection elements



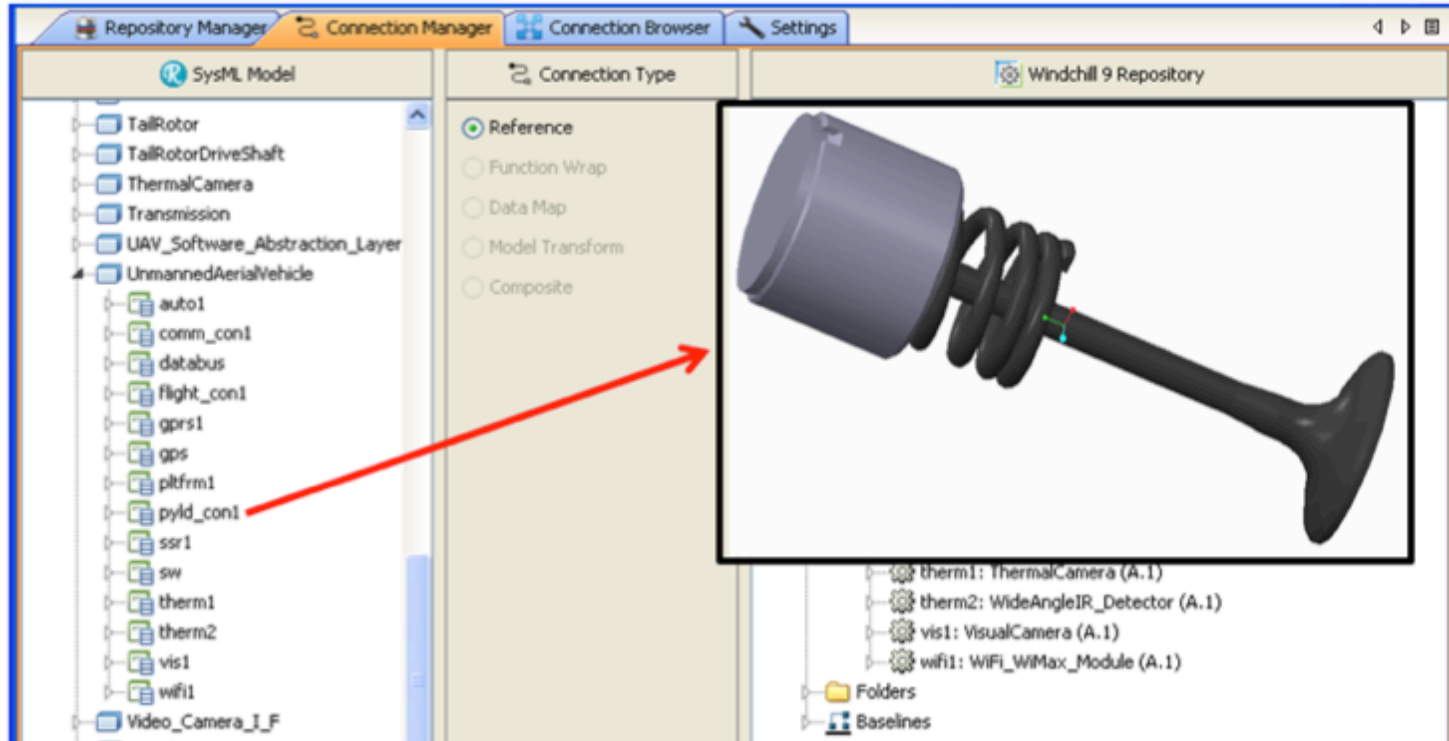
Model Transform Connections

+ Track/compare/sync element structure (multi-level)

3. Spectrum of Model-Based Connections

(Screenshots from Syndeia – 1/4)

Reference connection between SysML and
CAD to track/view 3D geometry



3. Spectrum of Model-Based Connections

(Screenshots from Syndeia – 2/4)



26th annual INCOSE
International Symposium

Edinburgh, UK
July 18 - 21, 2016

Data Map connection to get/compare mass props

Syndeia Dashboard (2.0.0) - Unmanned Aerial Vehicle

Repository Manager | Connection Manager | Connection Browser | Connection Summary | Comparison Result | Settings

SysML Model

- Automobile System
 - 1_FORMULA_SAE_RACECAR
 - 20_6950_10
 - 20_6950_10_MIR
 - 618132RS1_ASM_2
 - 618132RS1_ASM_2_MIR
 - 618132RS1_PART1_1
 - 618132RS1_PART1_1_MIR
 - 618132RS1_PART2_2
 - 618132RS1_PART2_2_MIR
 - 618132RS1_PART3_2

Connection Type

- Reference
- Function Wrap
- Data Map
- Model Transform

Creo

- 1_formula_sae_racecar.asm.115
- 1_formula_sae_racecar.asm.116
- 1_formula_sae_racecar.asm.117
- 1_FORMULA_SAE_RACECAR
 - MANIFOLD
 - SUSPENSION
 - DIFFERENTIAL
 - RR_CORNER
 - CENTER_SUPPORT
 - FRONT_FAIRING_COMPLETE
 - LF_CORNER
 - FRONT_FAN
 - FRONT_FAIRING
 - FLOORBOARD
 - SEAT
 - LR_CORNER
 - RF_CORNER
 - REAR_MOUNT
 - MOTOR
 - CHASSIS
 - FRONT_WING

Drag-n-drop to generate & connect

1_FORMULA_SAE_RACECAR

name	value
MANIFOLD	MANIFOLD
SUSPENSION	SUSPENSION
DIFFERENTIAL	DIFFERENTIAL
RR_CORNER	RR_CORNER
CENTER_SUPPORT	CENTER_SUPPORT
FRONT_FAIRING_COMPLETE	FRONT_FAIRING_COMPLETE
LF_CORNER	LF_CORNER
FRONT_FAN	FRONT_FAN
FRONT_FAIRING	FRONT_FAIRING
FLOORBOARD	FLOORBOARD
SEAT	SEAT
LR_CORNER	LR_CORNER
RF_CORNER	RF_CORNER
REAR_MOUNT	REAR_MOUNT
MOTOR	MOTOR
CHASSIS	CHASSIS
FRONT_WING	FRONT_WING

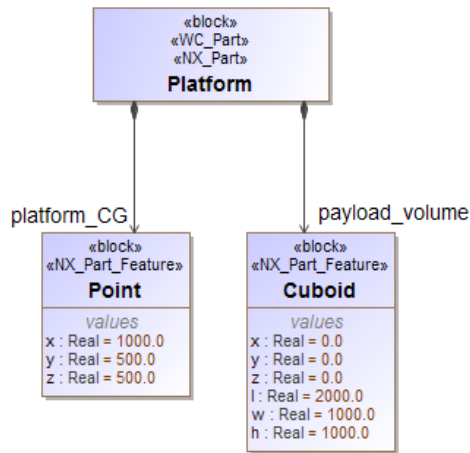
Creo Race Car

Example model from PTC Creo 3.0

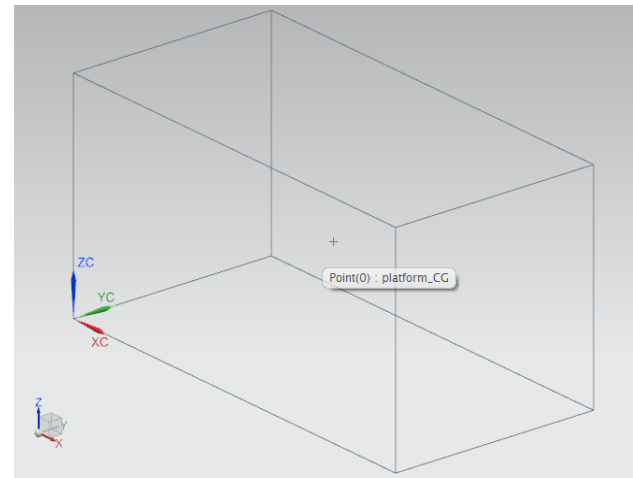
3. Spectrum of Model-Based Connections

(Screenshots from Syndeia – 3/4)

Model Transform connection to seed sub-system bounding boxes from property-based requirements



Seed system constraints (bounding boxes, keepout-zones,...) from the architecture



3. Spectrum of Model-Based Connections

(Screenshots from Syndeia – 4/4)



26th annual INCOSE
International Symposium

Edinburgh, UK
July 18 - 21, 2016

Compare and bi-directional sync across connections

Repository Manager Connection Manager Connection Browser Connection Summary Comparison Result Settings

Q- Type here to filter connections Clear Export to Excel

Conn ID	Source	Target	Latest Target	Comment
e3f03...	Unmanned Aerial Vehicle	000464/C;2-Unmanned Aerial Vehicle	000464/C;2-Unmanned Aerial Vehicle	The block Unmanned Aerial Vehic...
	wimax module : WiMax Module	wimax module : 000472/A;1-WiMa...	wimax module : 000472/A;1-WiMax M...	Part property wimax module and...
	visual camera : Visual Camera	visual camera : 000475/A;1-Visual ...	visual camera : 000475/A;1-Visual Ca...	Part property visual camera and ...
	trackers : Sensor			Part property trackers has no co...
	thermal camera : Thermal Camera	thermal camera : 000476/A;1-Ther...	thermal camera : 000476/A;1-Therma...	Part property thermal camera an...
	software : Software System	software : 000487/B;1-Software S...	software : 000487/B;1-Software Syst...	Part property software and part...
	payload controller : Payload Controller	payload controller : 000470/A;1-P...	payload controller : 000470/A;1-Payl...	Part property payload controller ...
	modem : Spread Spectrum Radio M...	modem : 000474/A;1-Spread Spec...	modem : 000474/A;1-Spread Spectru...	Part property modem and part o...
	ir detector : Wide Angle IR Detector	ir detector : 000477/A;1-Wide Ang...	ir detector : 000477/A;1-Wide Angle I...	Part property ir detector and pa...
	gps : GPS	gps : 000466/A;1-GPS	gps : 000466/A;1-GPS	Part property gps and part occu...
	gprs module : GPRS UMTS Module	gprs module : 000473/A;1-GPRS U...	gprs module : 000473/A;1-GPRS UMT...	Part property gprs module and p...
	flight controller : Flight Controller	flight controller : 000469/A;1-Fligh...	flight controller : 000469/A;1-Flight C...	Part property flight controller an...

[11:56:22] INFO Comparing SysML part property and Teamcenter part occurrence (BOM line with ref des) thermal camera.

Ready 11:56:55 AM 549M of 735M

4. Unified Framework for Model-Based Connections



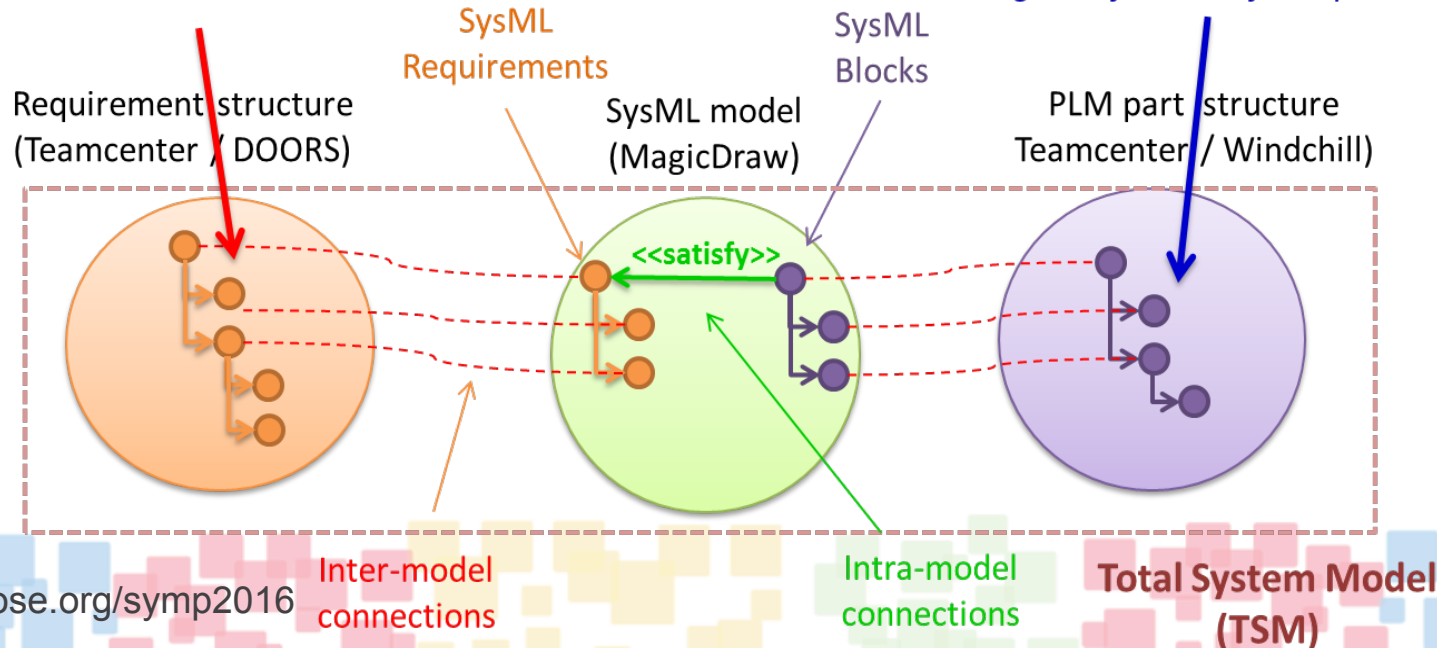
- A unified model-based engineering framework is needed to traverse both:
 - Inter-model connections (across model boundaries)
 - Intra-model connections (within model boundaries)

4. Unified Framework for Model-Based Connections

- Use Cases (example)

If I change this requirement, what is the downstream impact, e.g. to CAD models in PLM

What requirements does this part correspond to, and what is the upstream impact of changes or failures of this part?



5. From Traceability to Impact



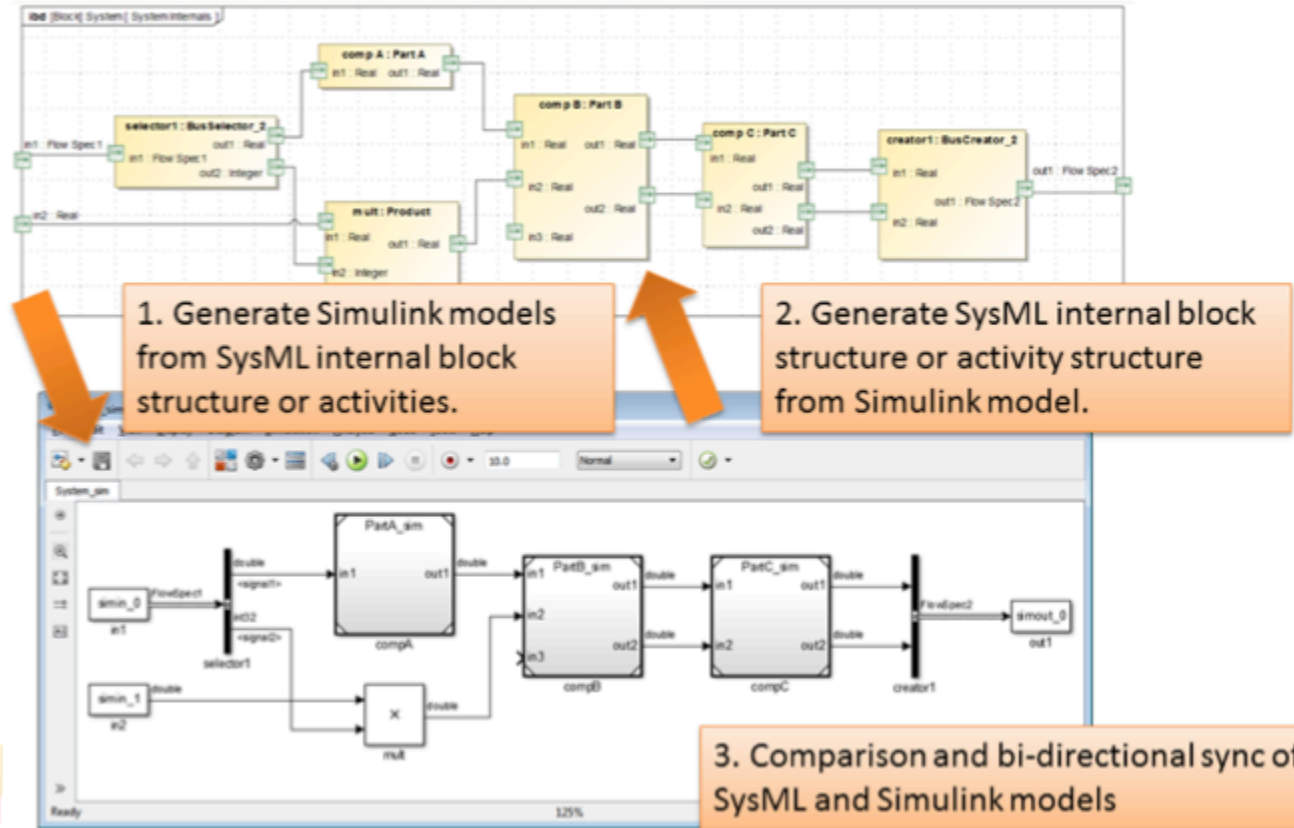
- Traceability is a starting point but not sufficient
- How do we create and manage millions of model-based connections for a real system?
 - Model transformations > Generate connections
- How do we propagate changes in one model to another model - quantitatively beyond suspect links?
 - Executable connections propagate changes

5. From Traceability to Impact

(Screenshot from Syndeia transformations)



System internal structure (SysML) used for generating and sync'ing executable simulation models (Simulink) and inter-model connections



6. Many Users, Many Views

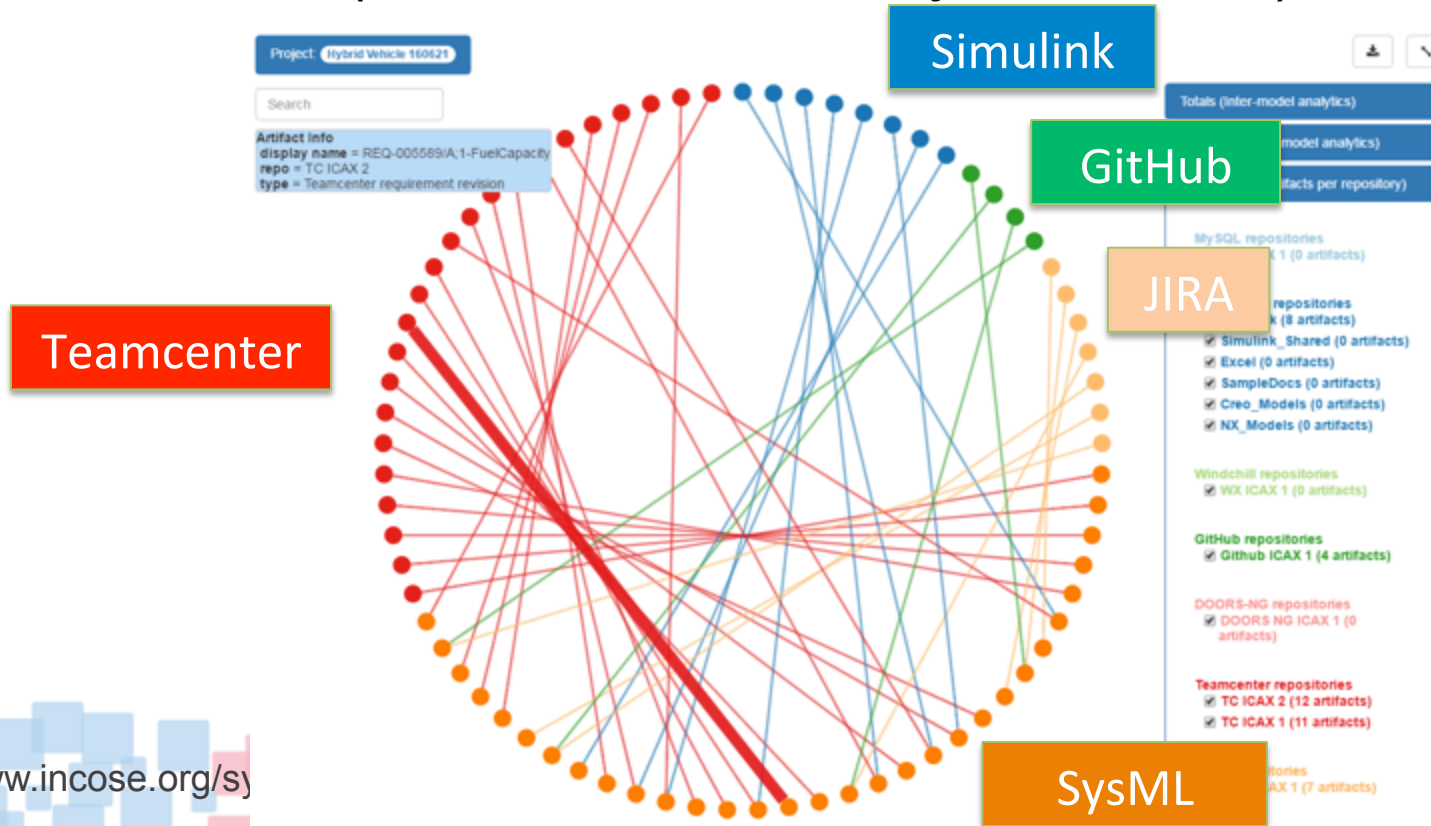


- Stakeholders need to visualize and query the Total System Model for different purposes
 - What system functions are planned to satisfy a reqt.?
 - What system elements implement a given function?
 - What test cases are planned to verify a requirement?
 - What functions would be affected if a part fails?
 - Is there a traceability for reqt. R to mechanical part M

6. Many Users, Many Views

Viewing all inter-model connections

(Screenshots from Syndeia – 1/3)



6. Many Users, Many Views

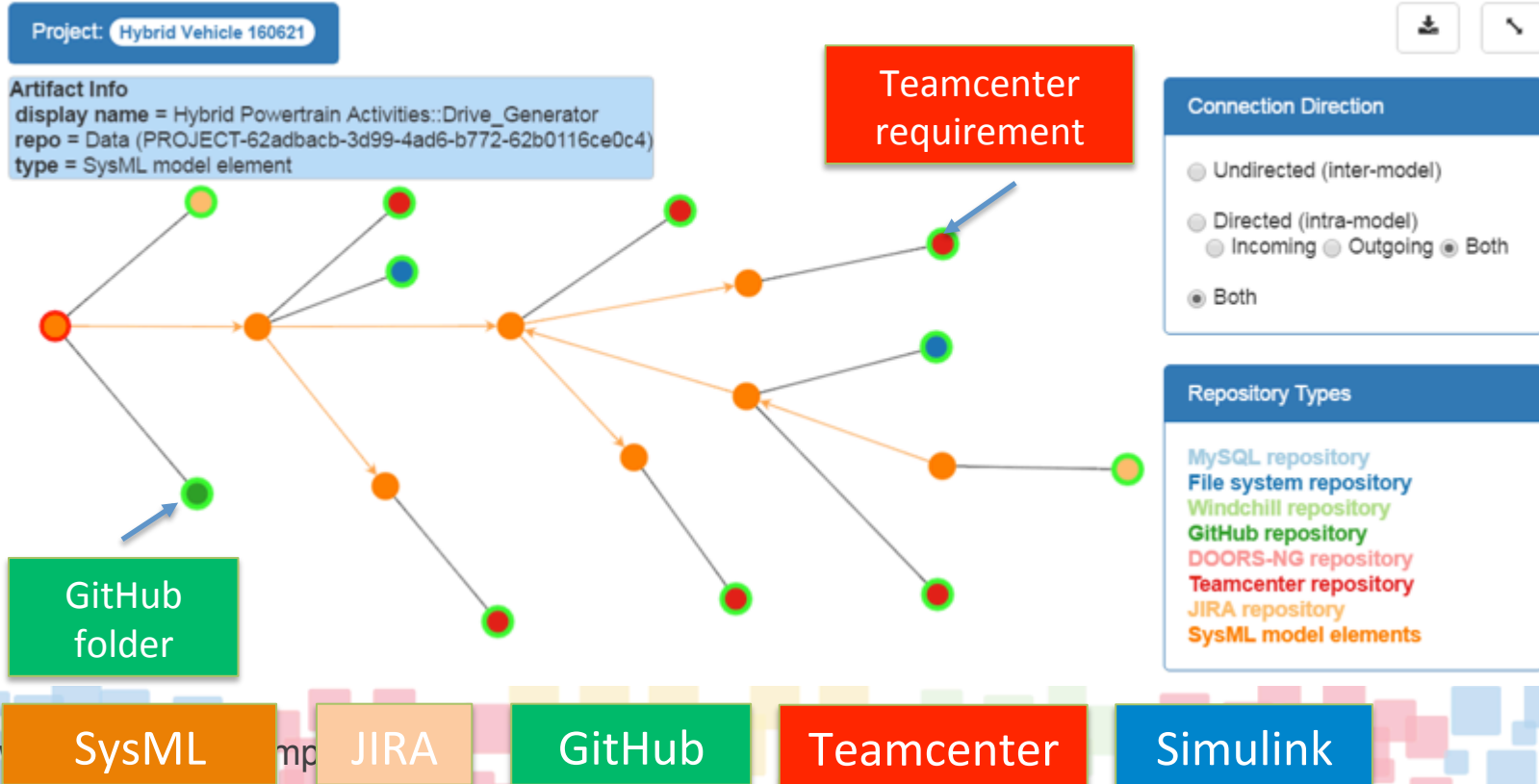
Explore inter- and intra-model connections

(Screenshots from Syndeia – 2/3)



26th annual INCOSE
international symposium

edinburgh, UK
July 18 - 21, 2016

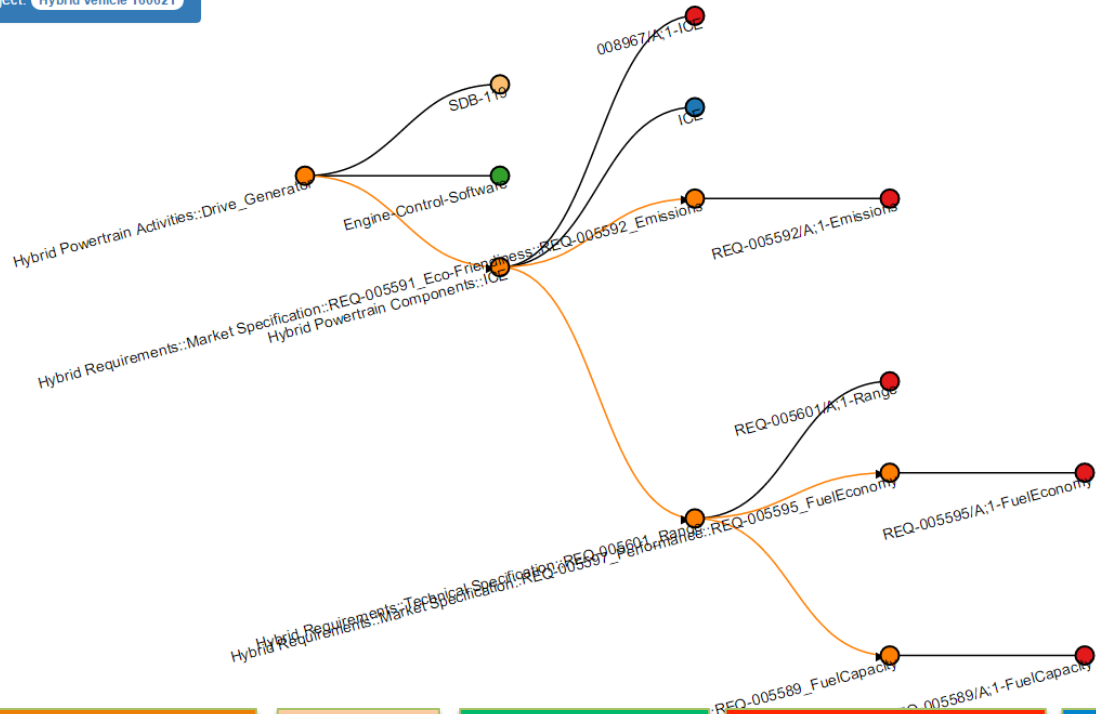


6. Many Users, Many Views

Explore inter- and intra-model connections

(Screenshots from Syndeia – 3/3)

Project: Hybrid Vehicle 160621



Connection Direction


- Undirected (inter-model)
- Directed (intra-model)
- Both

Repository Types

- MySQL repository
- File system repository
- Windchill repository
- GitHub repository
- DOORS-NG repository
- Teamcenter repository
- JIRA repository
- SysML model elements

Birmingham, UK
10 - 21, 2016

Contents

- Introduction
- 6 principles of MBSE++
- Short video illustration 
- Summary
- Q & A



MBSE++ Illustration using Syndeia



- YouTube Video

<https://youtu.be/SHsNrrWiFDE>

Summary



- *Graphs* are a fundamental abstraction for MBSE++ (nodes = model elements, and edges = inter-/intra-model relationships)
- *Total System Model* is a graph connecting all engineering disciplines across the lifecycle, a key enabler for MBSE++
- Presented 6 fundamental principles of MBSE++
- *Syndeia* = Software platform for MBSE++

Questions and Comments

Corresponding Author

Manas Bajaj, PhD

manas.bajaj@intercax.com

+1-404-775-4287

www.linkedin.com/in/manasbajaj



intercax



syndeia



/company/intercax-llc



intercax

