

May 19, 2008  
IIE Solutions • Vancouver



# Integrating Product and Process Design Using SysML

*Presenter*

Leon McGinnis - Georgia Tech

presentation version v1.1

# Collaborative Effort

## Primary Current Team



- Lockheed Martin
  - Sandy Friedenthal
- Deere & Co.
  - Roger Burkhart
- Georgia Institute of Technology (GIT)
  - Russell Peak, Chris Paredis, Leon McGinnis, & co.
  - Leveraging collaborations in PSLM Center SysML Focus Area (see next slide)

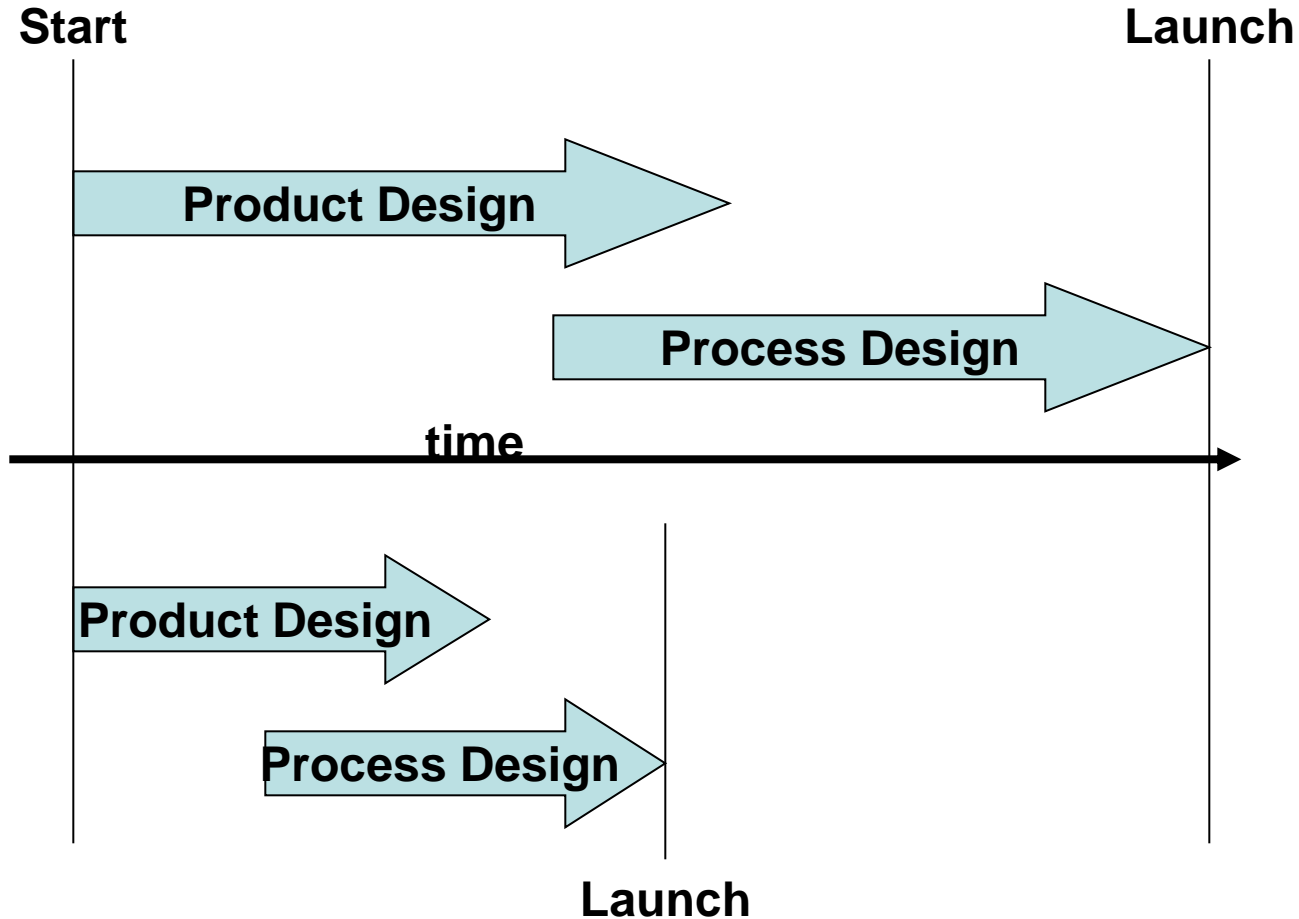
- SysML-related projects:
  - Boeing, Deere, Lockheed, NASA, NIST, TRW Automotive, ...
- Other efforts based at GIT:
  - NSF Center for Compact & Efficient Fluid Power
  - SysML course development
    - For Professional Masters in SE program, continuing ed. short course, ...
  - Other groups & labs (EIS, Virtual Factory, ...)
  - Vendor collaboration (tool licenses, support, ...)
- Consortia & other GIT involvements:
  - INCOSE Model-Based Systems Engineering (MBSE) effort
  - NIST SE Tool Interoperability Plug-Fest
  - OMG (SysML, ...)
  - PDES Inc. (Model-Based Enterprise, APs 210, 233, ...)
- Commercialization efforts:
  - [www.VentureLab.gatech.edu](http://www.VentureLab.gatech.edu)-based start-up:  
tools for executable SysML parametrics

# Contents

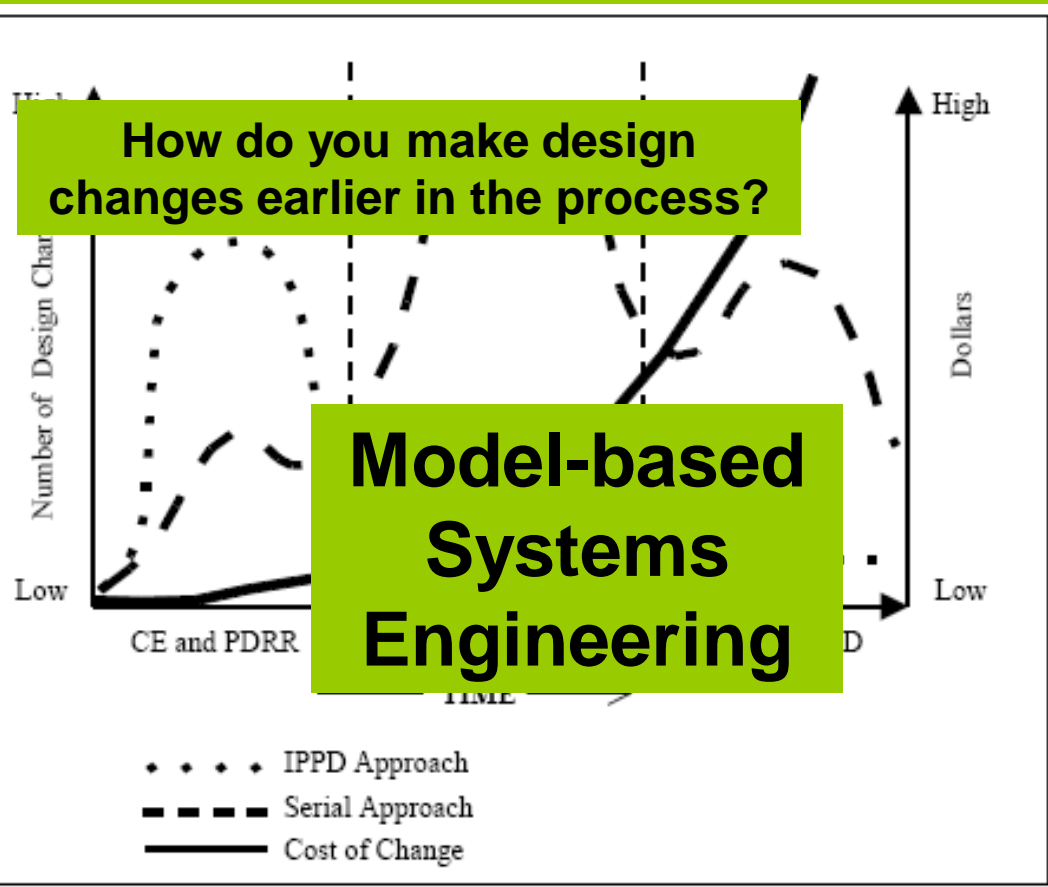


- ➔ ● The Challenge
- Demonstration project
- Technical Approach
  - Techniques and Testbeds
  - SysML
- Implementation
- Future developments

# Faster Design



# Better/Cheaper Design



# “To Be” Design Process



- Both Product Design and Process Design, individually, are done faster, cheaper, better
  - ***Tighter integration of design and analysis***
- Better integration of product design with process design
  - ***Common product model***

# Contents



- The Challenge
- • Demonstration project
- Technical Approach
  - SysML
  - Techniques and Testbeds
- Implementation
- Future developments



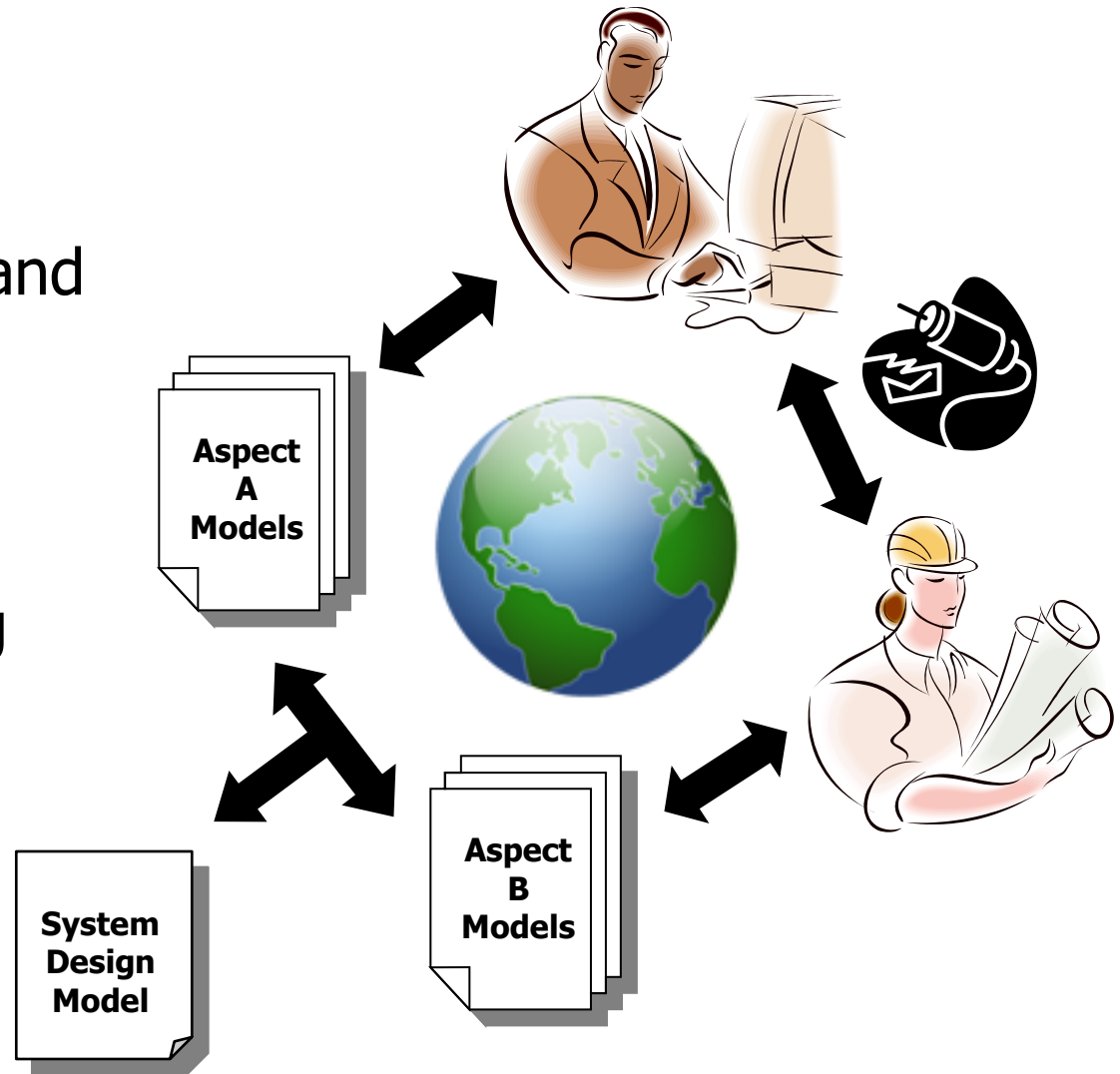
# Demonstration Project



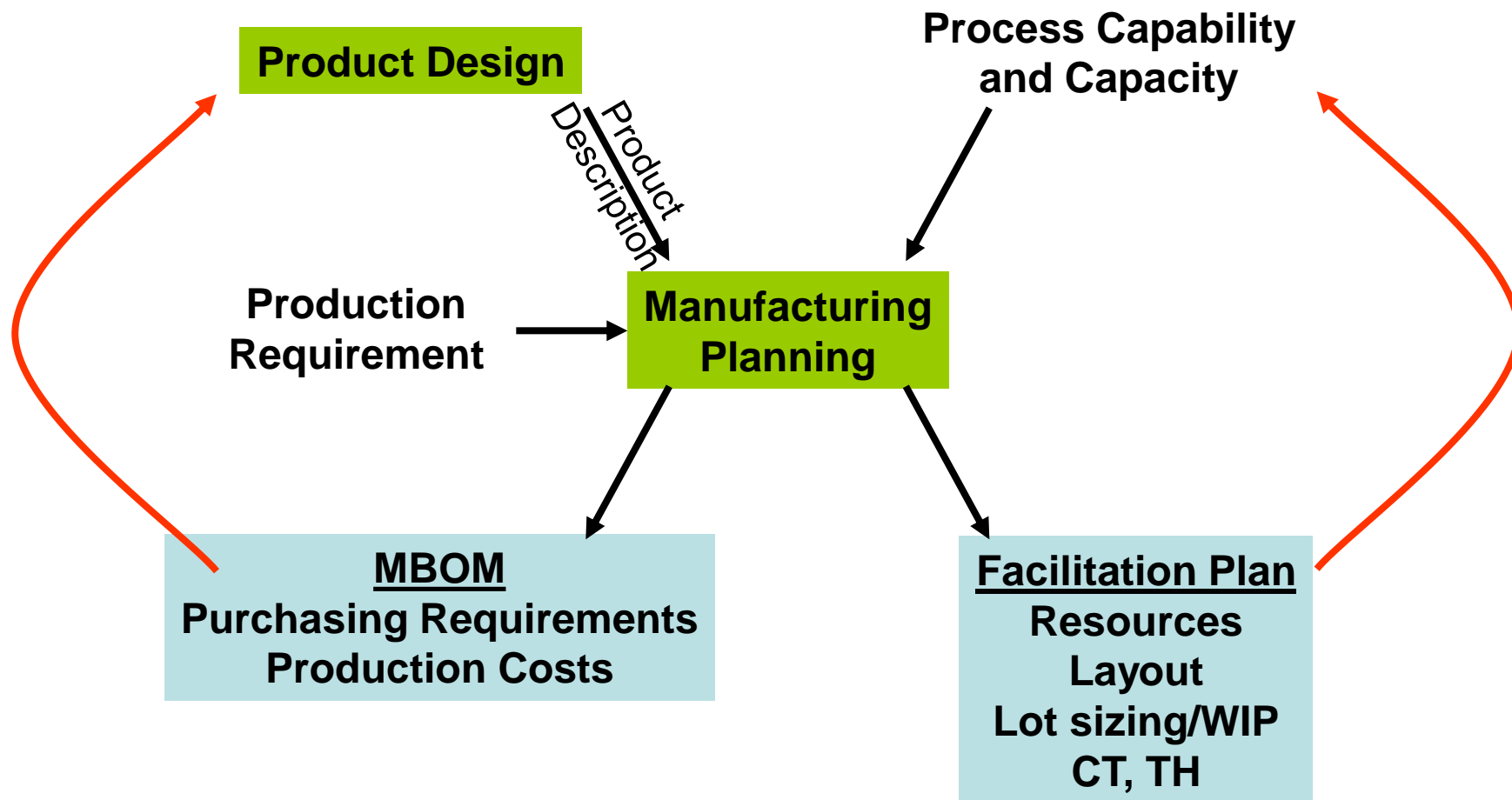
# Model-Based Systems Design



- Increasing system complexity
- Distributed design and modeling
- Models of multiple system aspects
- Information sharing between system models



# IPPD: An IE Perspective



# How to make it happen?



**Data standards and interoperable software do not, by themselves, assure integration!**

**Semantic content is the critical factor for integration:**

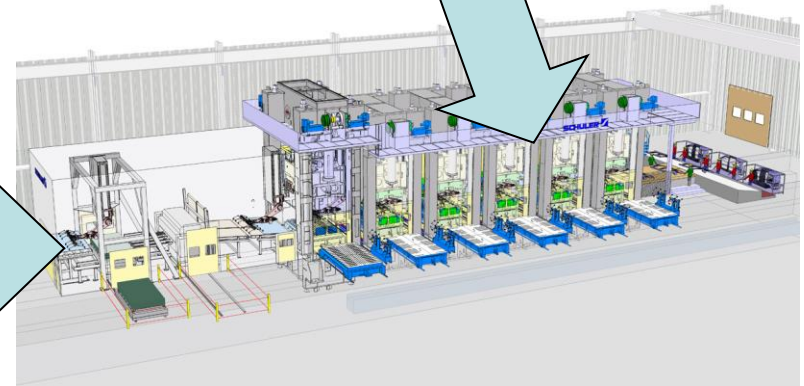
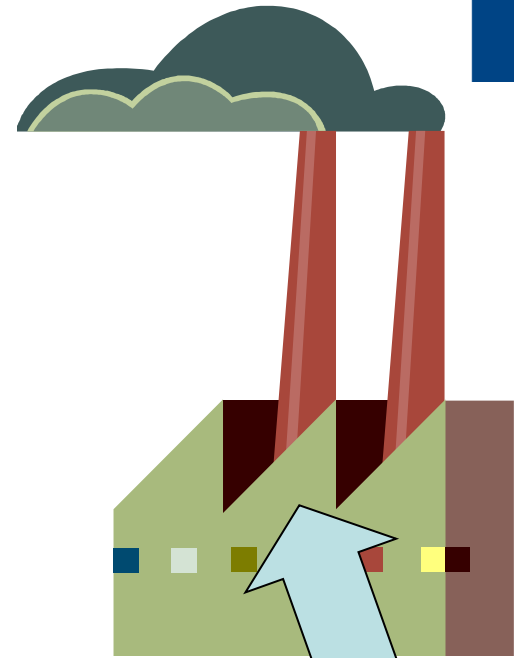
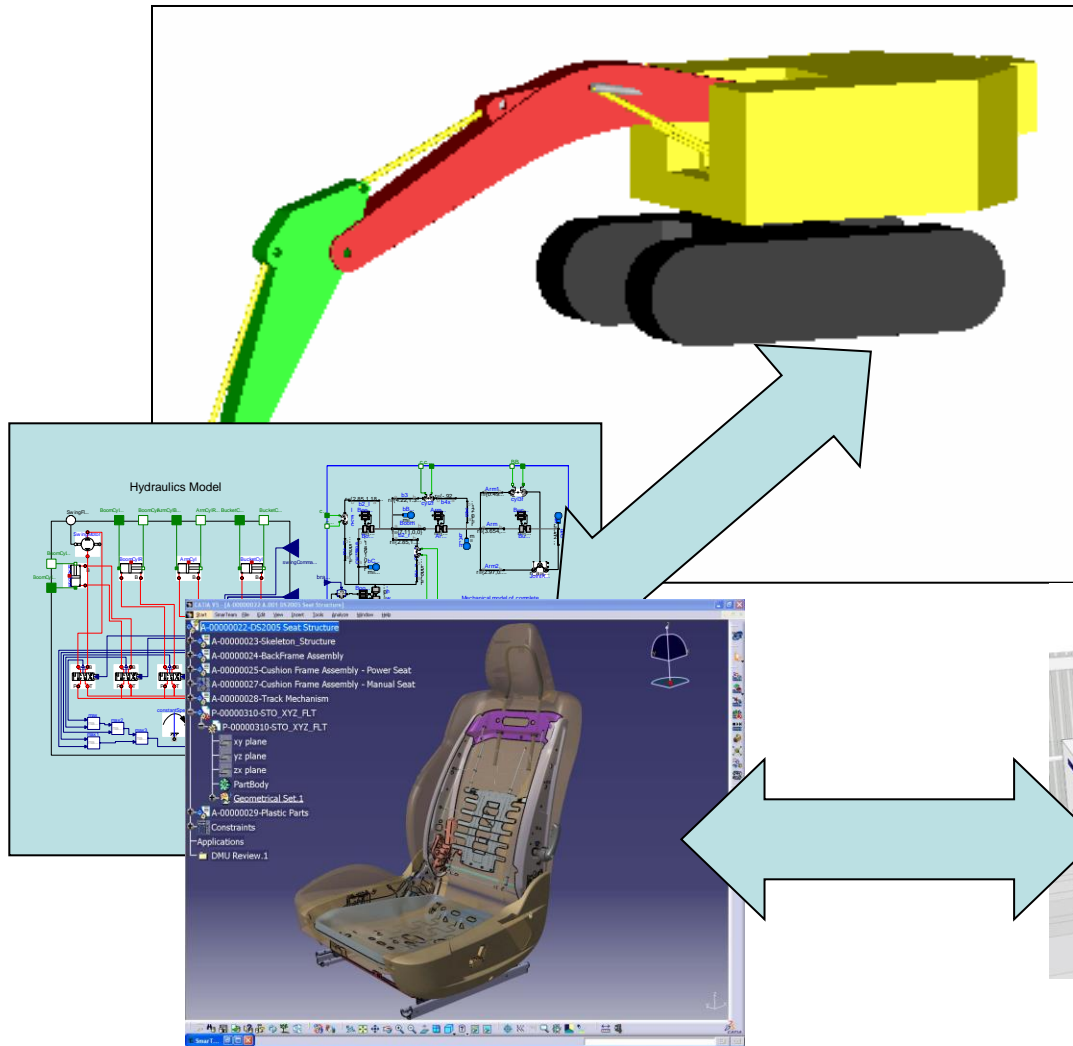
- of design with analysis
- of product with process

# Semantic Content



- The weight of a part depends upon its dimensions
- The transport time between two workstations depends upon both the distance and the behavior of the transport system
- The behavior of a WIP buffer depends on the dispatch policies

# The Challenge

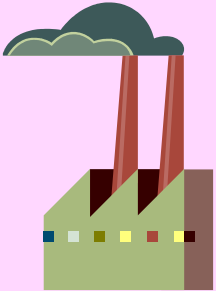
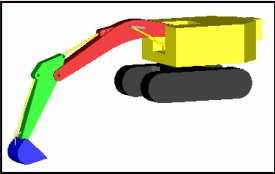
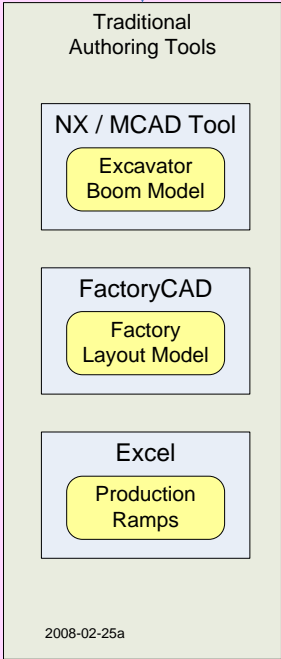


# Contents



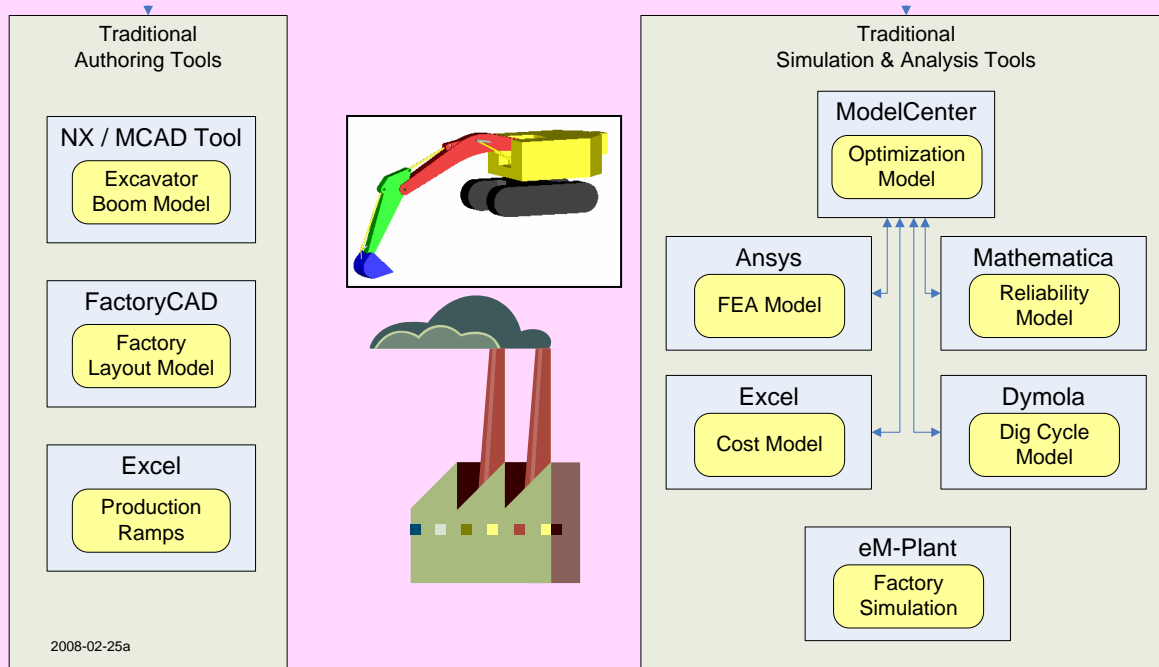
- The Challenge
- Demonstration project
- • Technical Approach
  - Tool/Model Framework
  - SysML
- Implementation
- Future developments

# *GIT Testbed: Tools and Models*

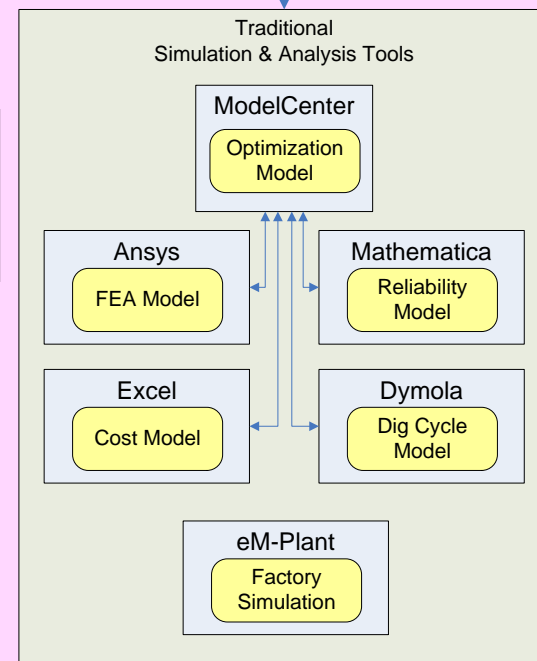
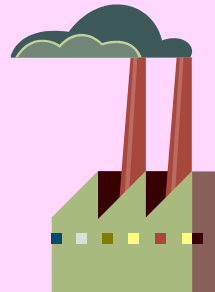
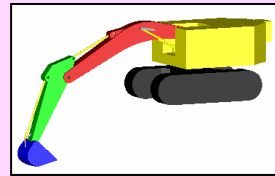
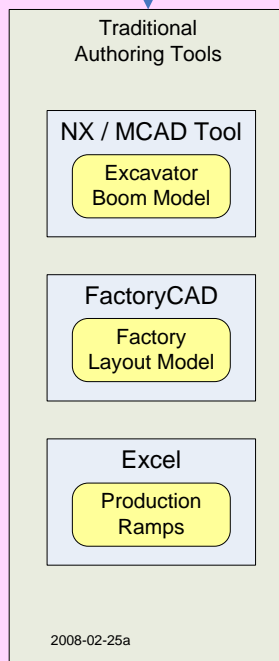
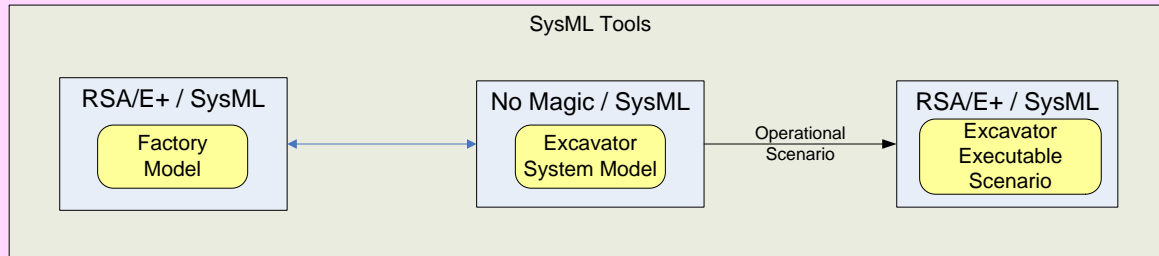




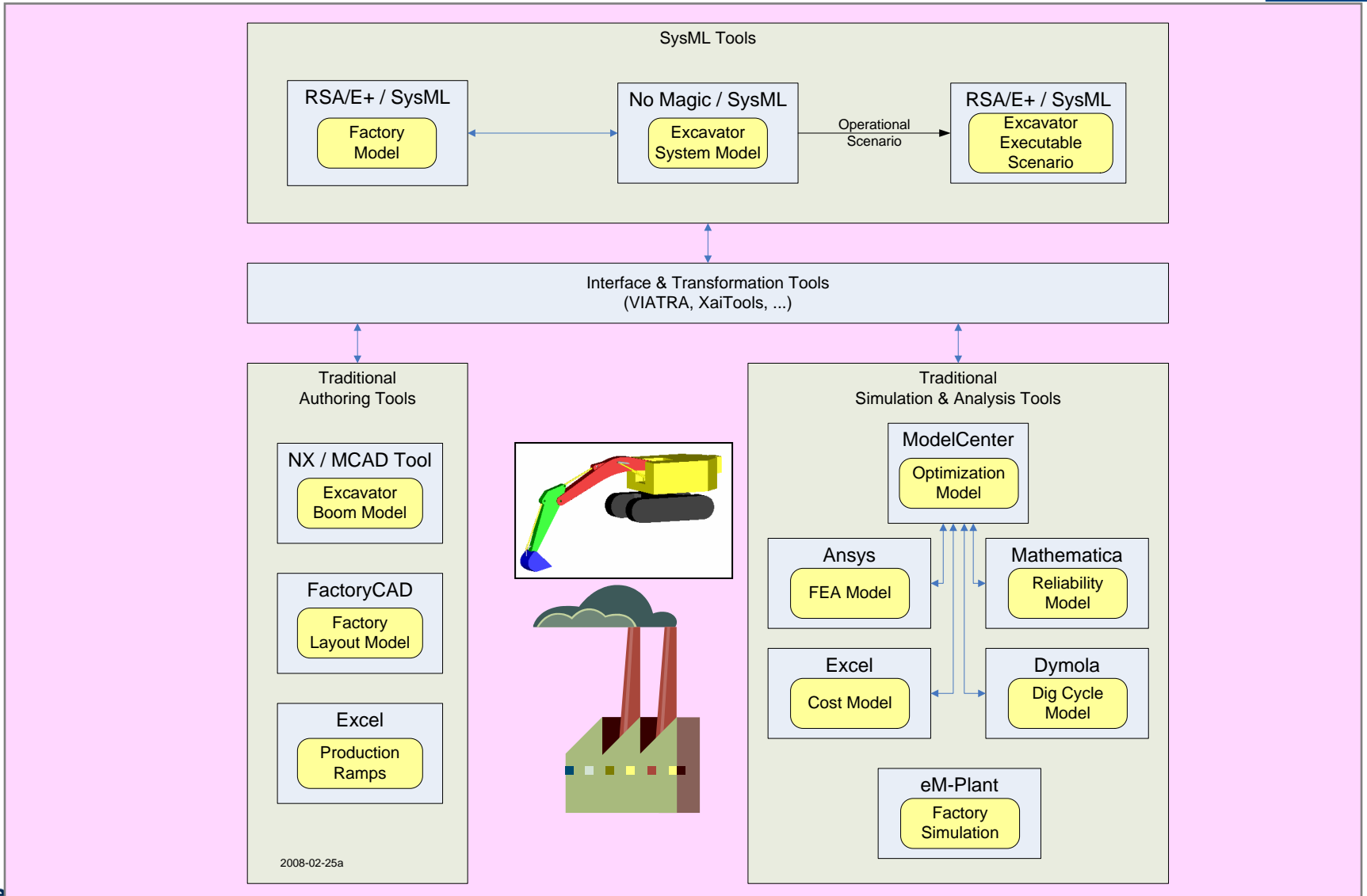
# *GIT Testbed: Tools and Models*



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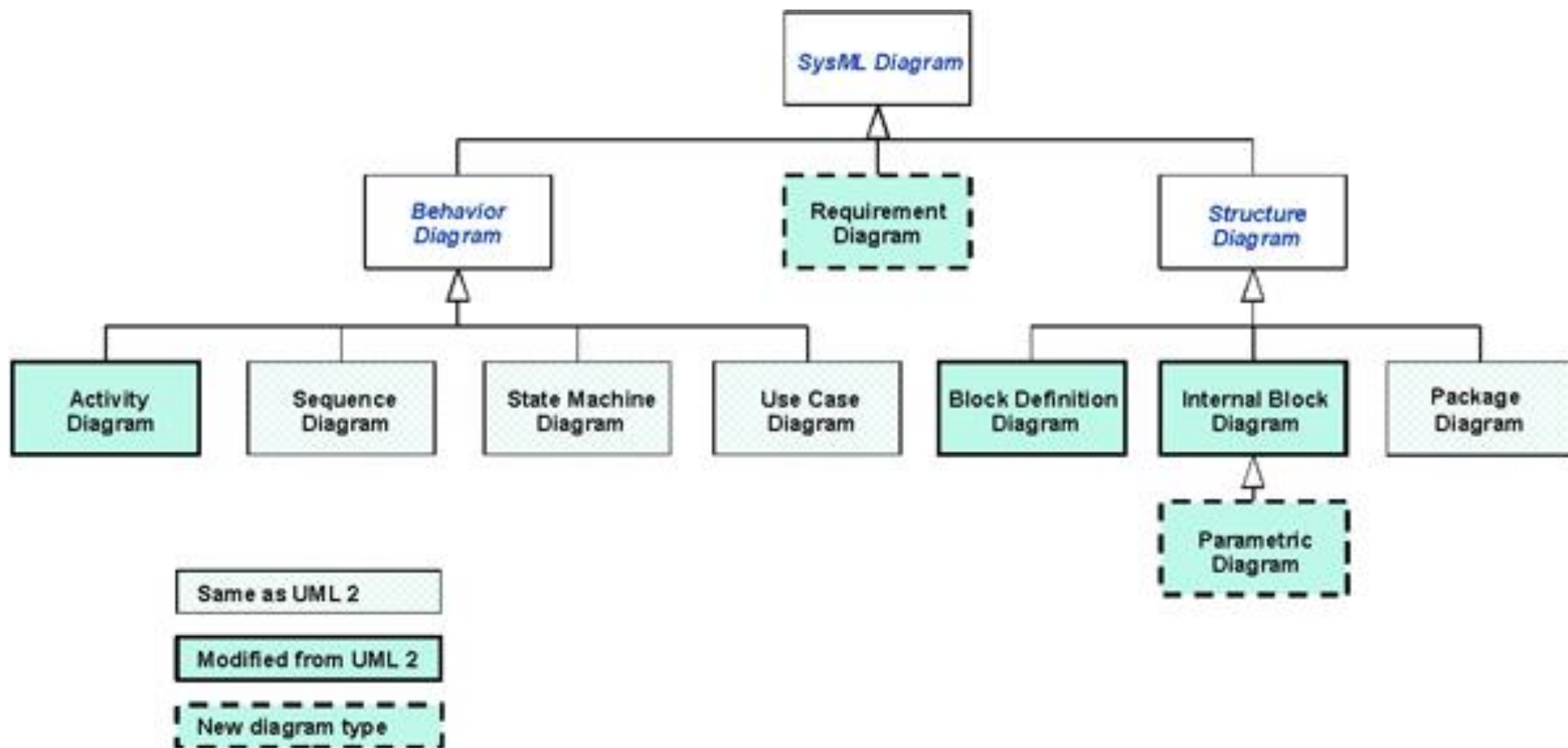




## What is SysML (cont.)

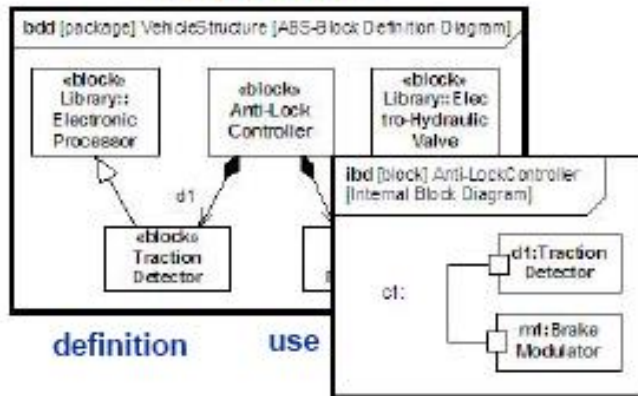


- ***Is*** a visual modeling language that provides
  - Semantics = meaning
  - Notation = representation of meaning
- ***Is not*** a methodology or a tool
  - SysML is methodology and tool independent



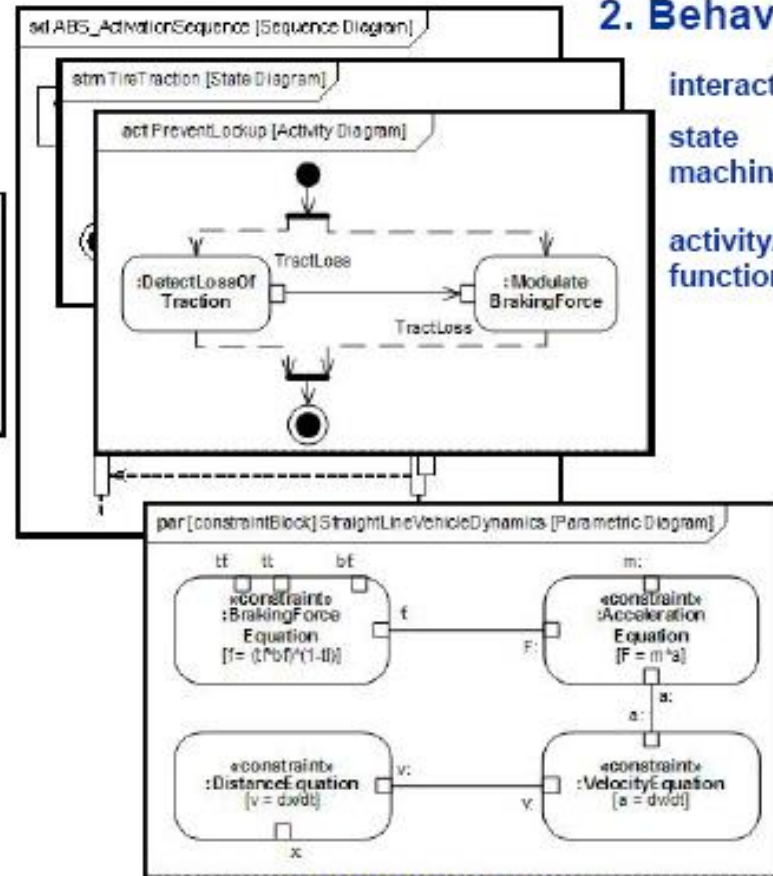
From: <http://www.omg.sysml.org/>

## 1. Structure



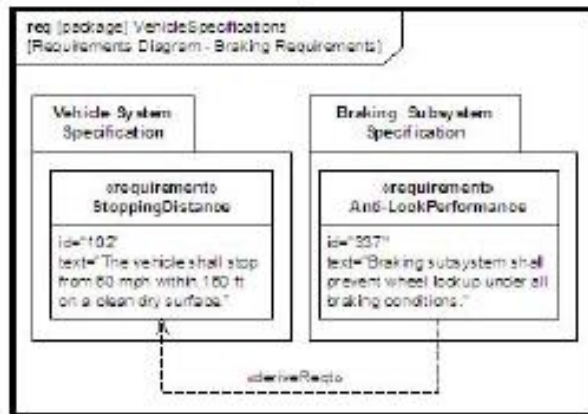
definition use

## 2. Behavior



interaction  
state machine  
activity/  
function

## 3. Requirements



## 4. Parametrics

7/26/2007

Copyright © 2006,2007 by Object Management Group.

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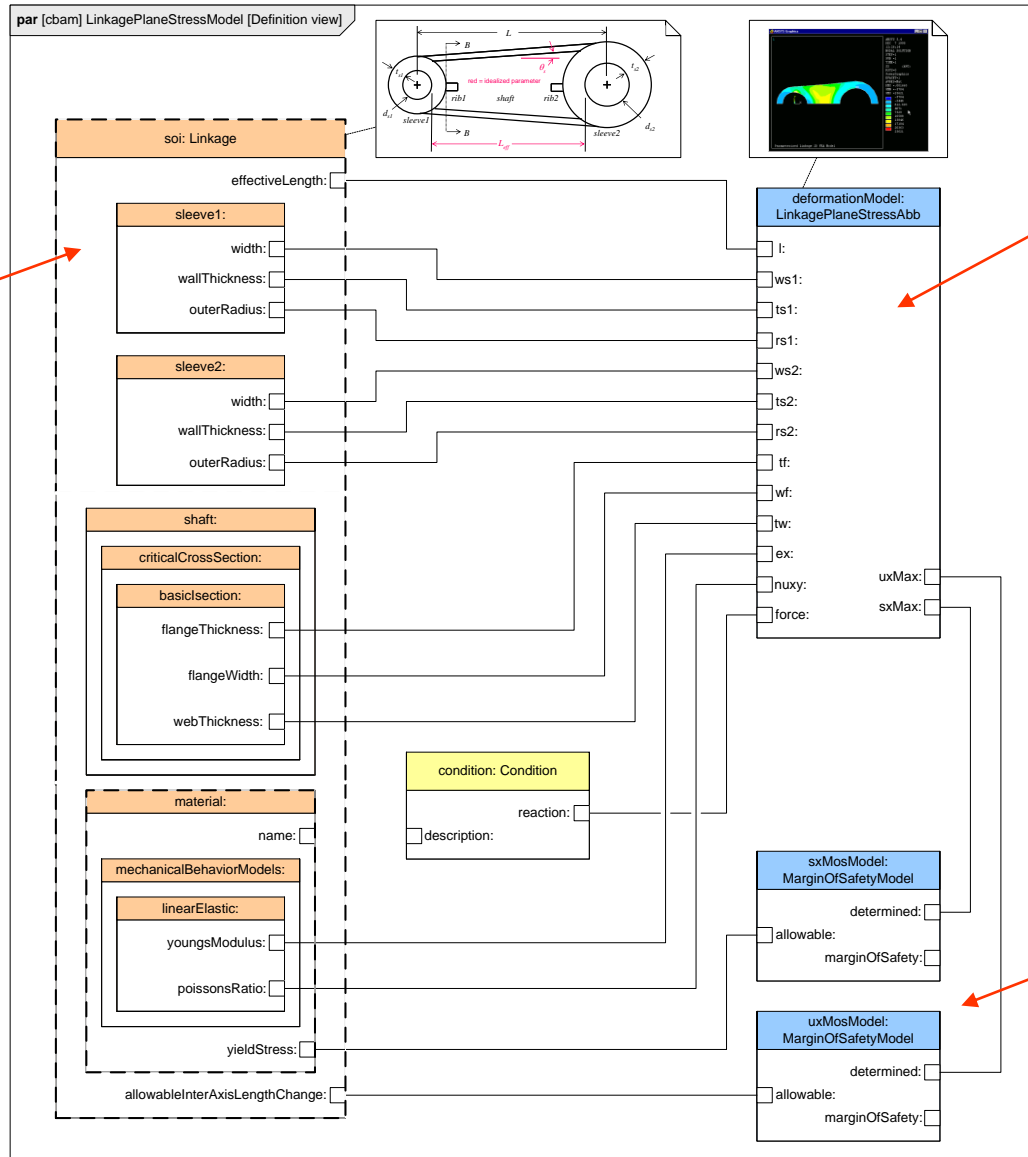
The challenge is discovering how best to use SysML to enhance product/process design integration

# "Wiring Together" Diverse Models via SysML

## Level 1: Intra-Template Diversity



Mechanical  
CAD model



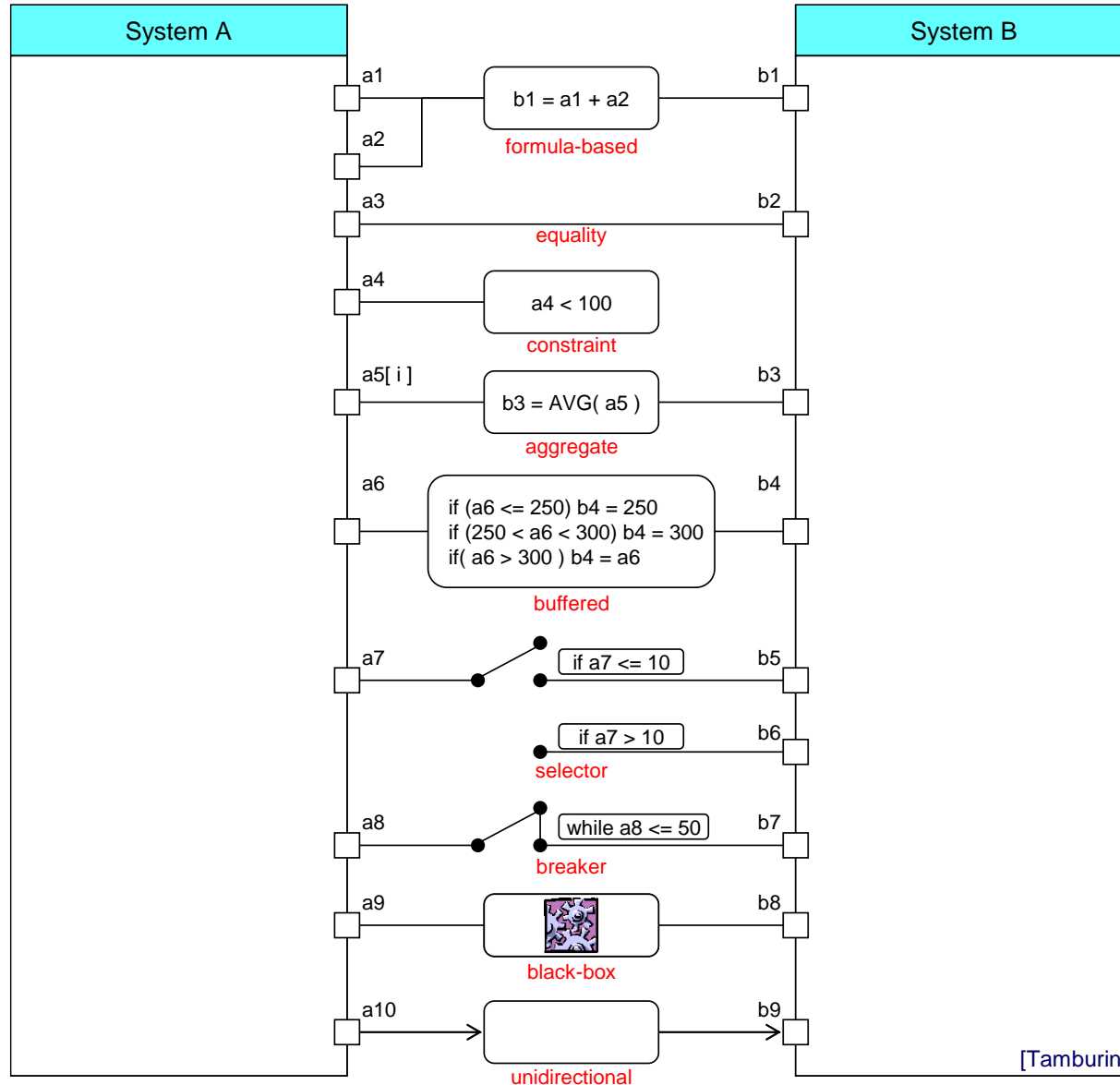
CAE model  
(FEA)

Symbolic  
math models



# Diverse Types of Relations ...

(partially supported to date)

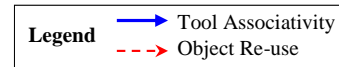


# "Wiring Together" Diverse Models via SysML

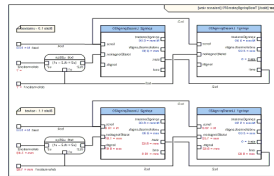
## Level 2: Inter-Template Diversity



Naval Systems-of-Systems (SoS) Panorama—An Envisioned Complex Model Interoperability Problem Enabled by SysML/COBs/MRA



### Optimization Templates



### System Description Tools & Resources

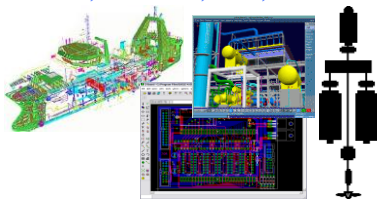
### Simulation Building Blocks

### Simulation Templates of Diverse Behavior & Fidelity

### Simulation Solvers

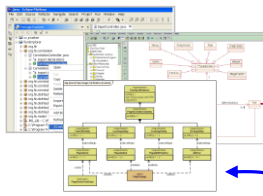
#### ECAD & MCAD Tools

Tribon, CATIA, NX, Cadence, ...



#### Systems & Software Tools

DOORS, Studio, MagicDraw, Eclipse, ...

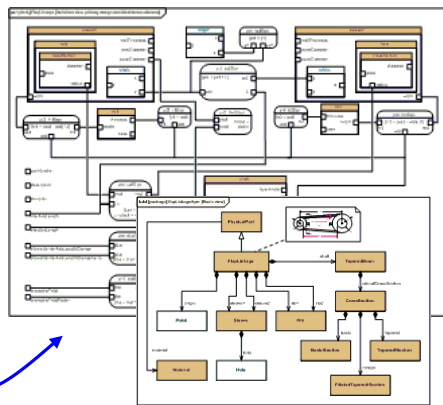


#### Operation Mgt. Systems



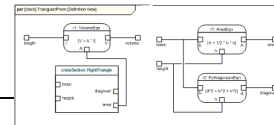
#### Libraries & Databases

Classification Codes, Materials, Personnel, Procedures, ...



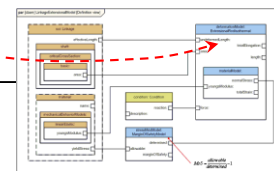
### Augmented Descriptive Models

#### Evacuation Mgt.



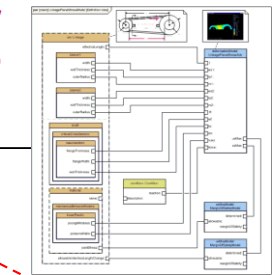
2D

#### Propeller Hydro-dynamics

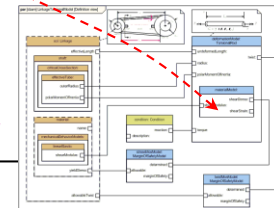


3D

#### Damaged Stability



#### Navigation Accuracy

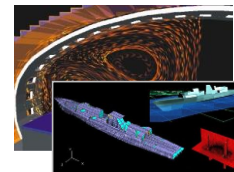


#### Evacuation Codes

Egress, Exodus, ...

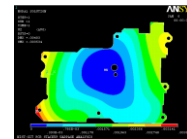
#### General Math

Mathematica, Maple, Matlab ...



#### CFD

Flotherm, Fluent, ...



#### FEA

Abaqus, Ansys, Nastran, ...

#### Discrete Event

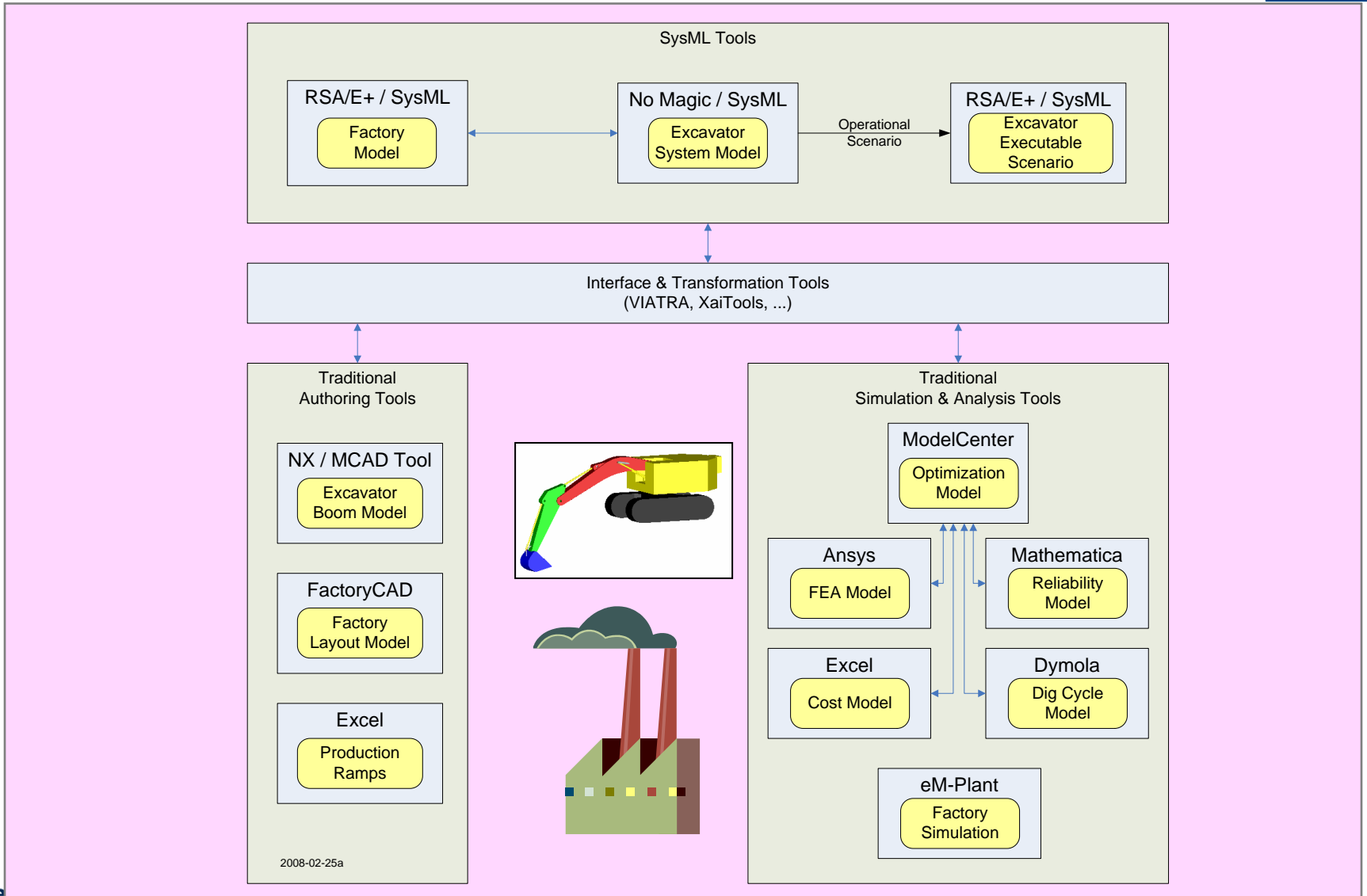
Arena, Quest, ...

# Contents



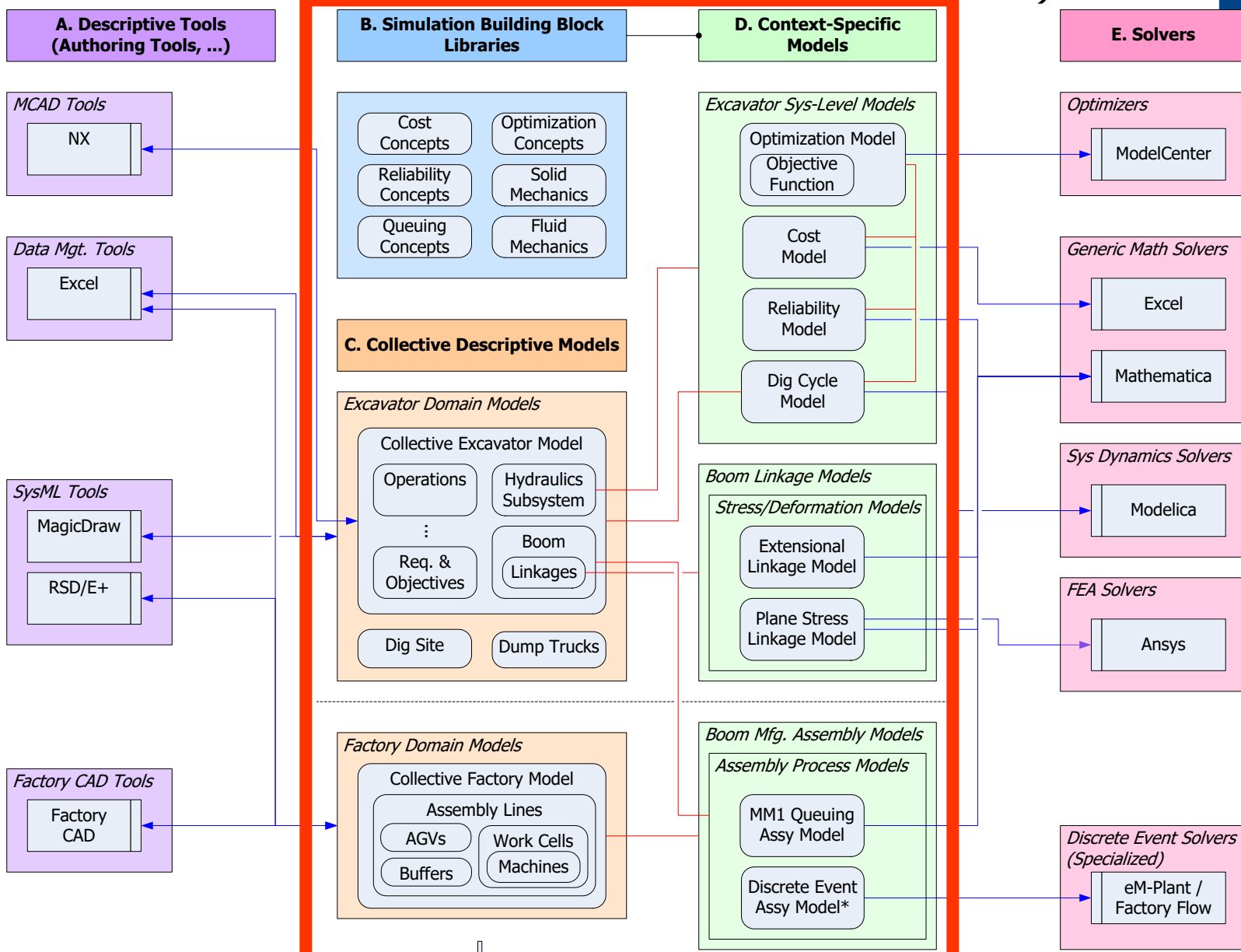
- The Challenge
- Demonstration project
- Technical Approach
  - Techniques and Testbeds
  - SysML
- ➔ • Results
- Future developments

# *GIT Testbed: Tools and Models*



# Excavator Modeling & Simulation Environment

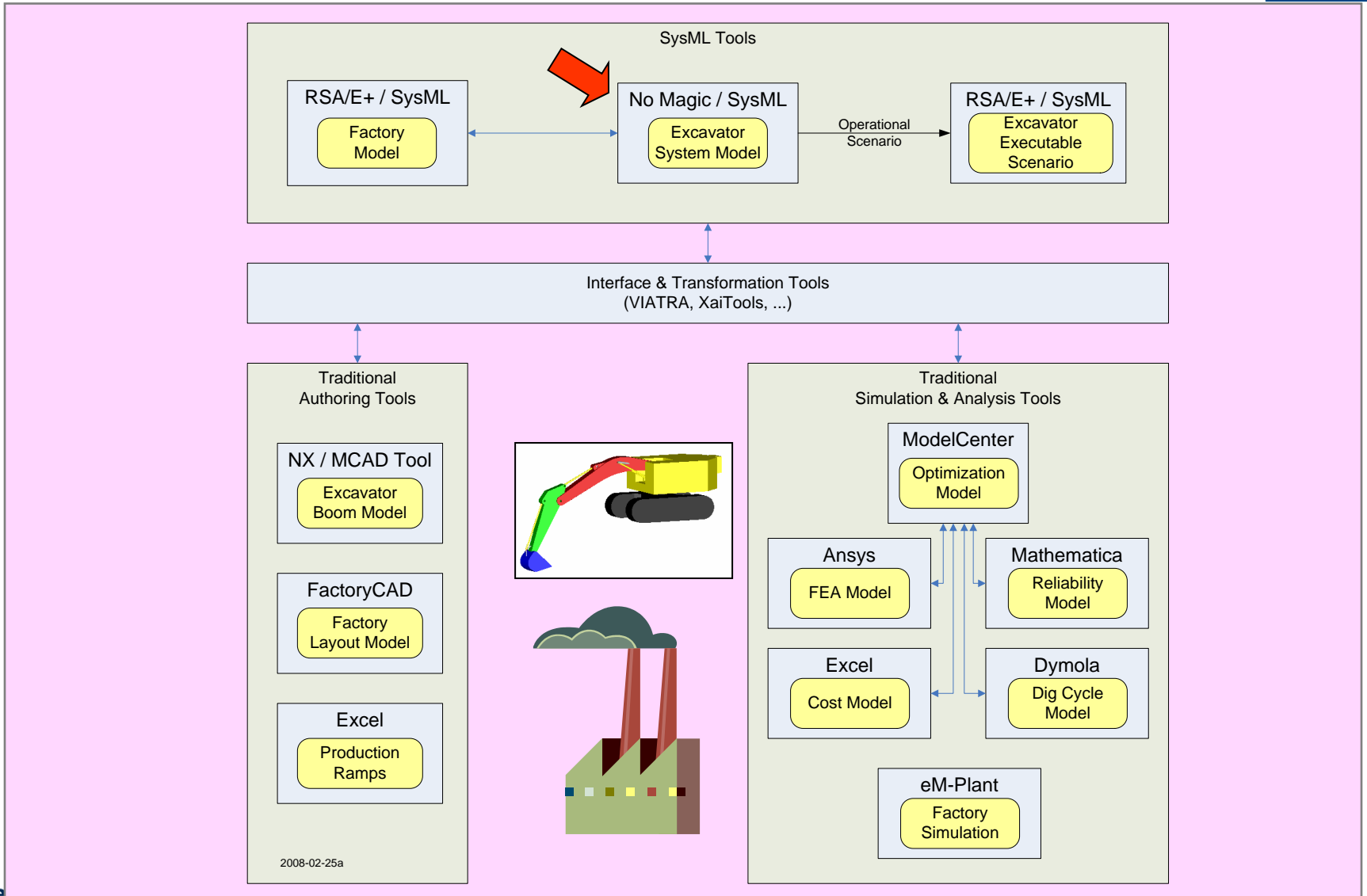
## *GIT Testbed: Pattern View (Interoperability Panorama)*



**Notes & Legend**

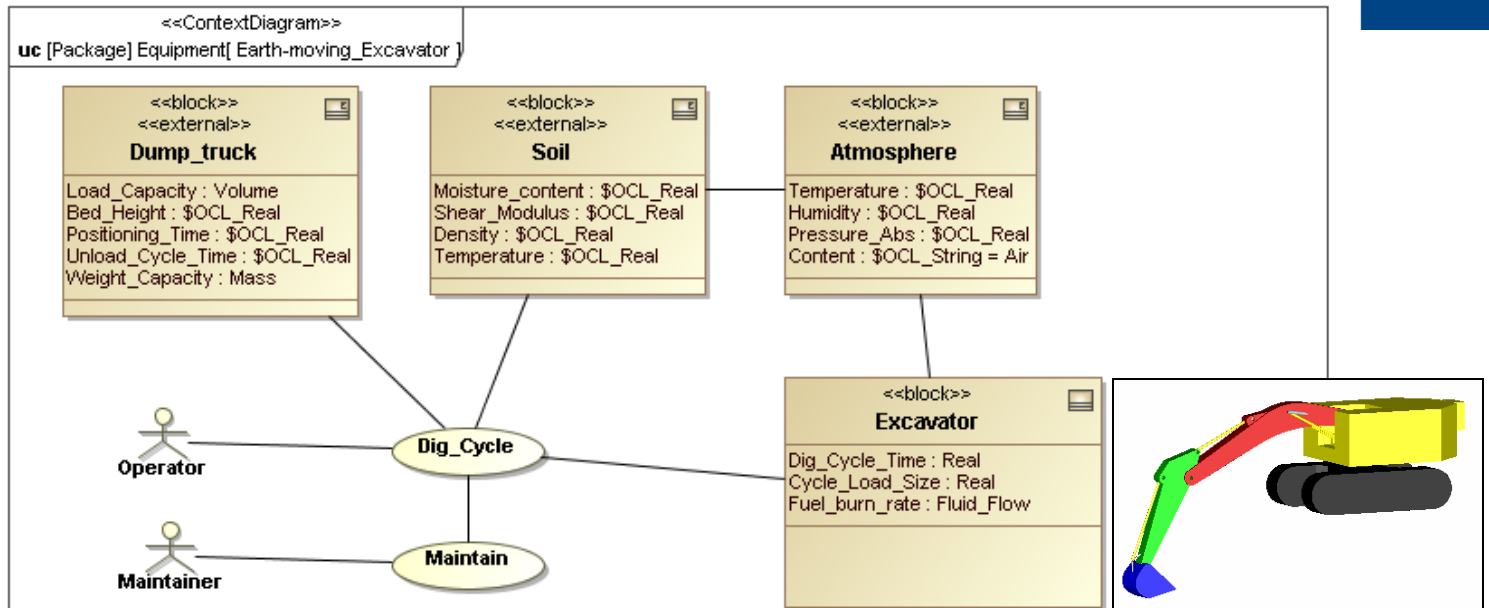
- 1.) All models shown are SysML models unless otherwise noted.
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# GIT Testbed: Tools and Models



# Excavator Operational Domain

## Top-Level Context Model



**Excavator Description**

The Excavator is used as a part of a larger enterprise designed to perform earth removal. An excavator is assigned to remove dirt from a specific location and place it into a truck for transport to a new location. The excavator operates in a dig cycle mode to perform this operation.

The Dump Truck is used to receive dirt and move and unload it when it becomes within a scoop of full volume or mass capacity.

The Soil is what is removed by the excavator, and may vary in consistency and is uncertain in properties, as well as depends on atmospheric conditions for some properties.

The Atmosphere affects the soil, as well as is used by the Excavator Drive-train to produce mechanical energy.

The operator controls the excavator position, velocity, and loading characteristics.

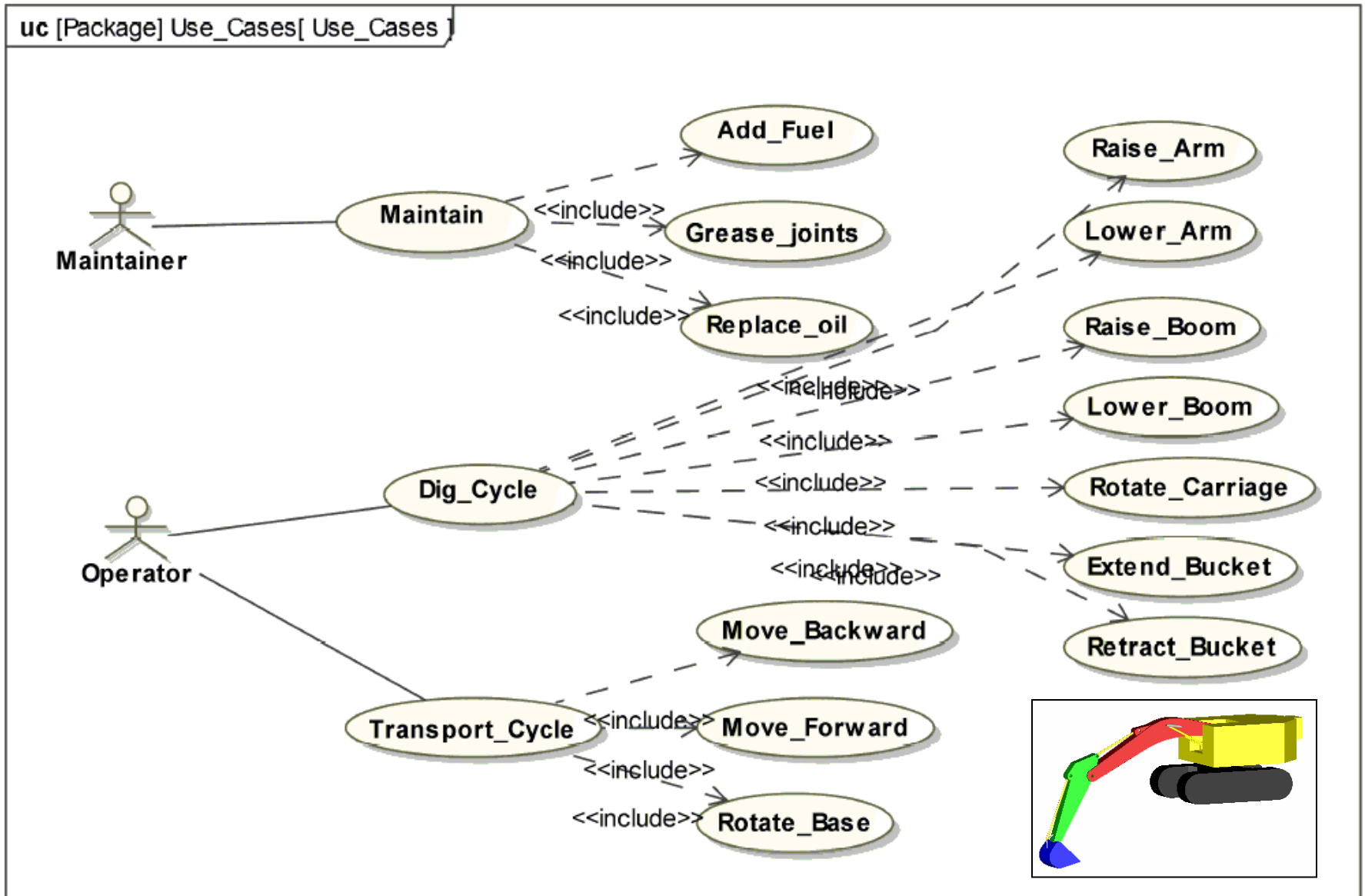
The maintainer accesses the excavator to replenish fuel, oil, and grease, as well as perform long-term maintenance.

The Dig\_Cycle use case governs the actions of the excavator as it removes dirt from the ground and places it in the truck.

The Maintain use case governs the timeline and periods for which maintenance must occur. Typically this timeline is much greater than the length of time required to fill a truck from multiple dig cycles, and is at a minimum a daily startup check.

# Excavator Operational Domain

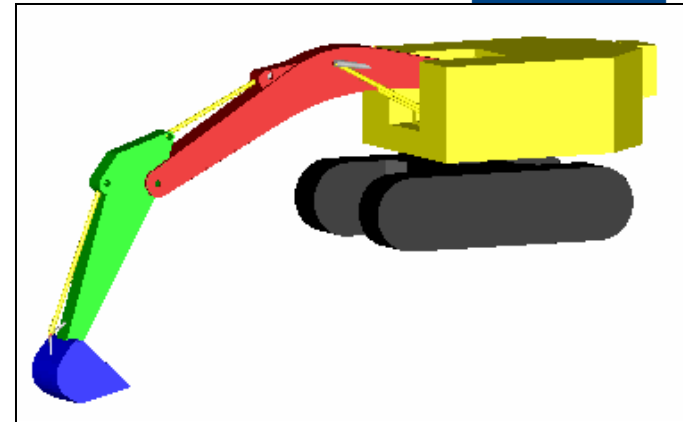
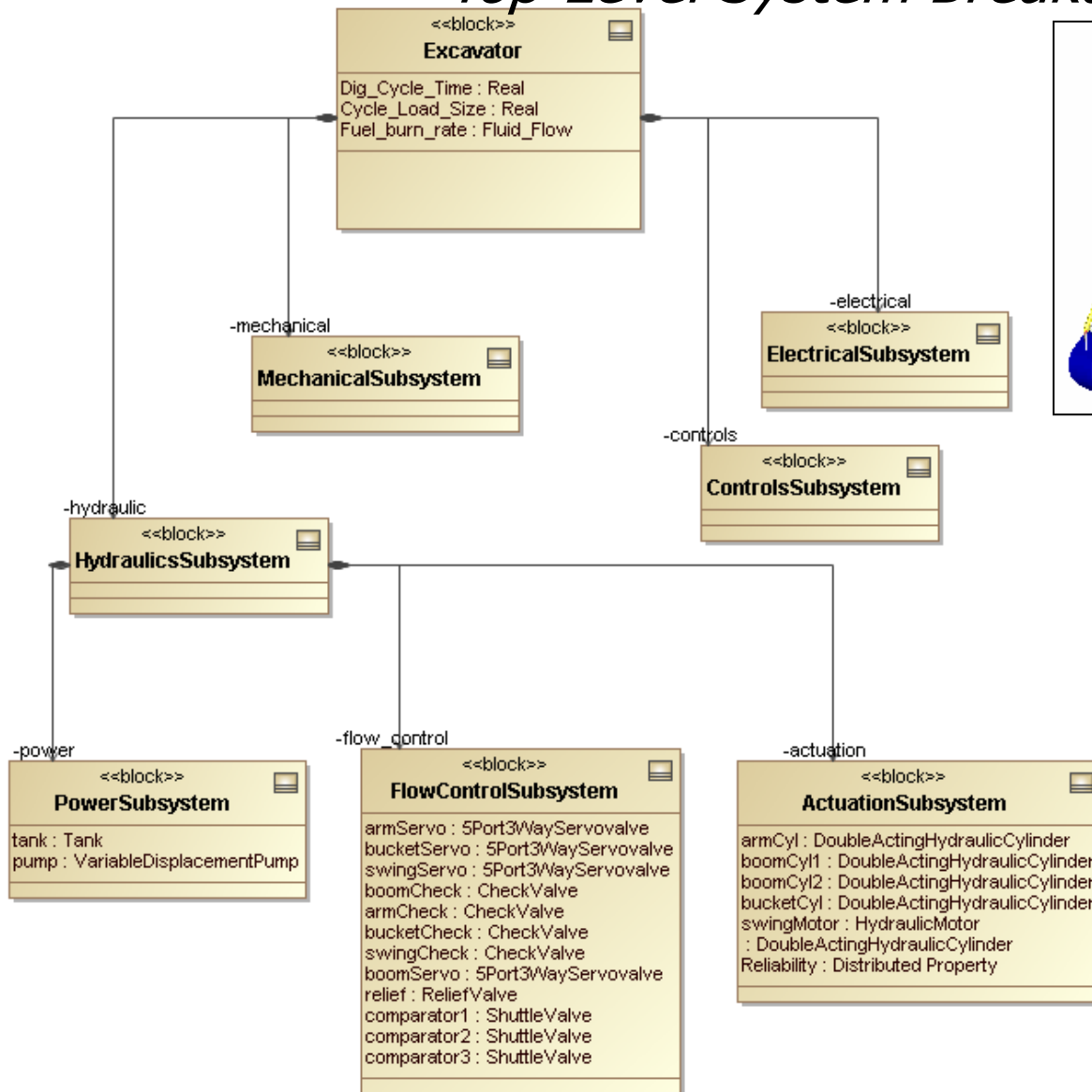
## Top-Level Use Cases





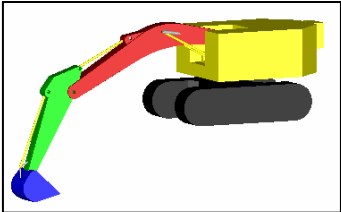
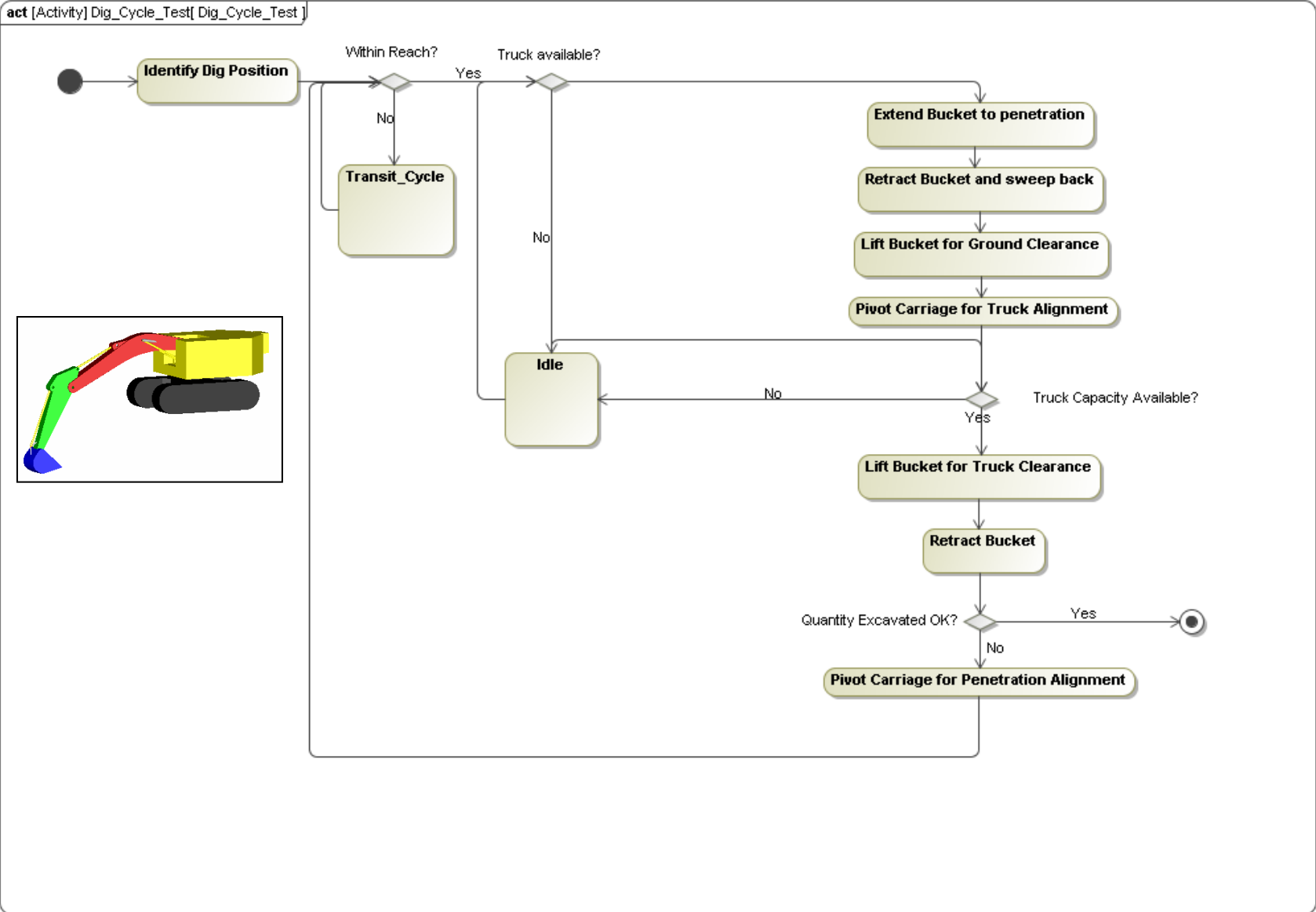
# Excavator Test Case

## *Top-Level System Breakdown*

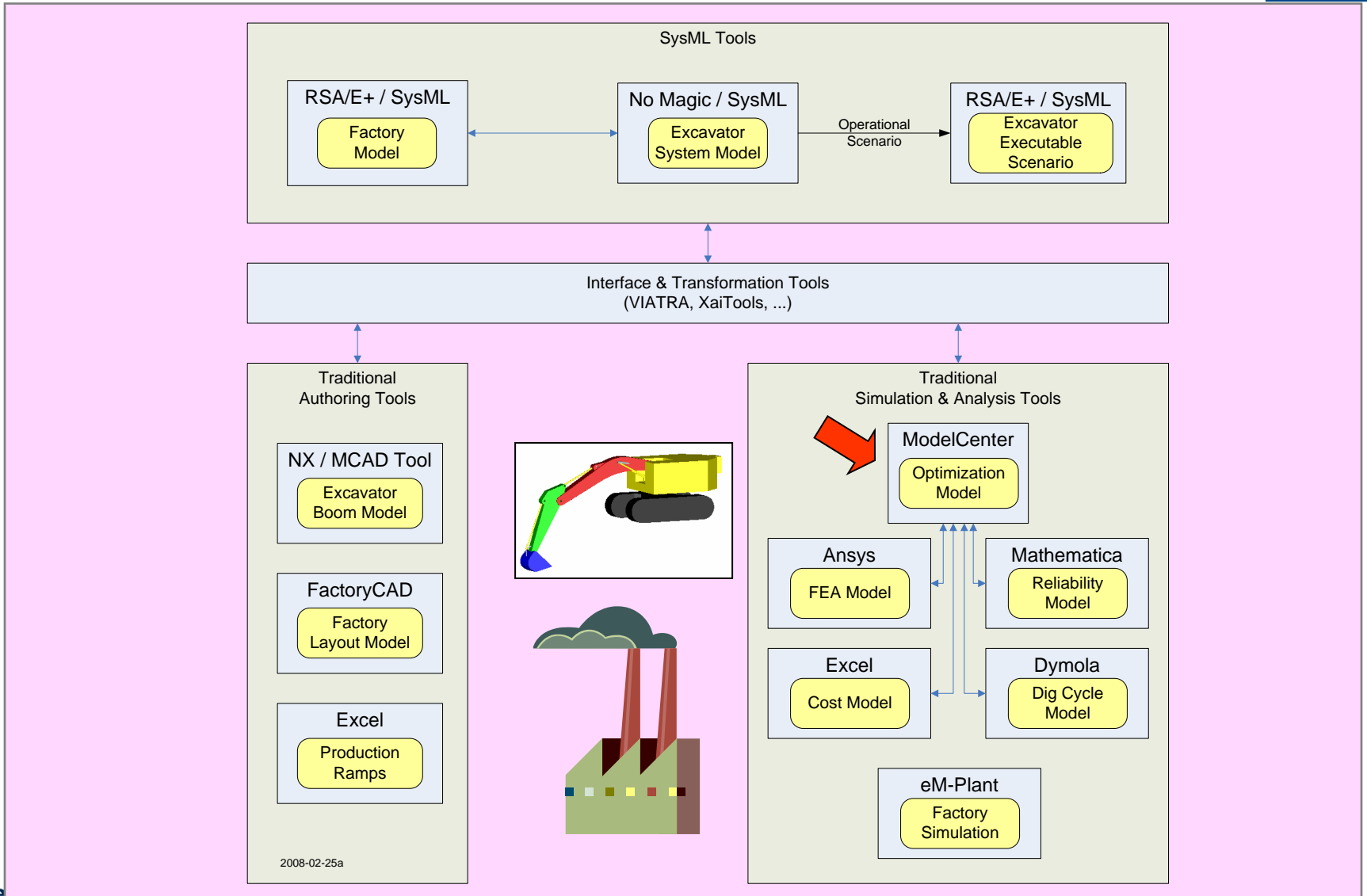


# Excavator Dig Cycle

## Activity Diagram



# GIT Testbed: Tools and Models

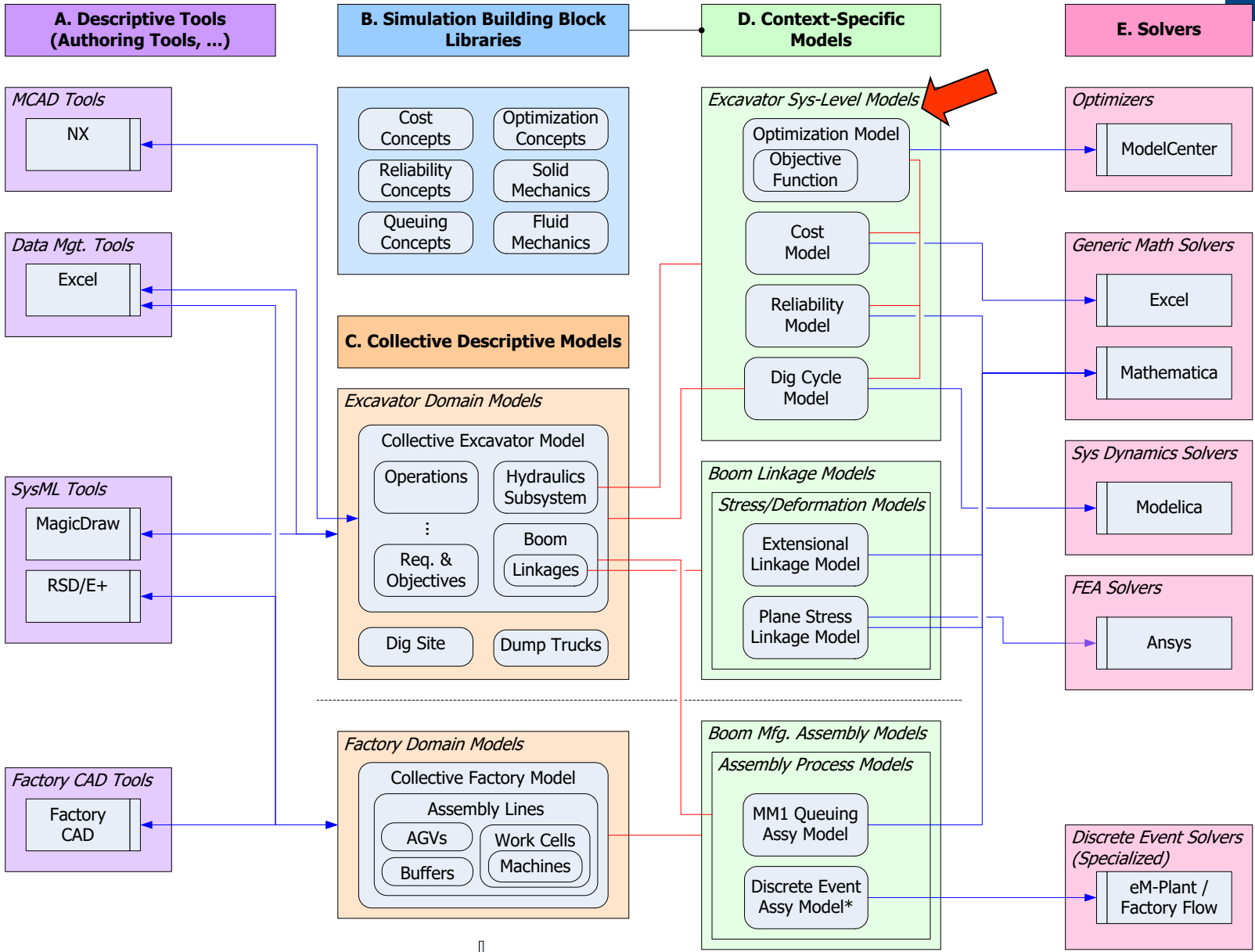


# Excavator Modeling & Simulation Environment

## *GIT Testbed: Pattern View (Interoperability Panorama)*



2008-01-25  
\* This model is in a GIT prototype tool (with a schema based on its offline SysML model).

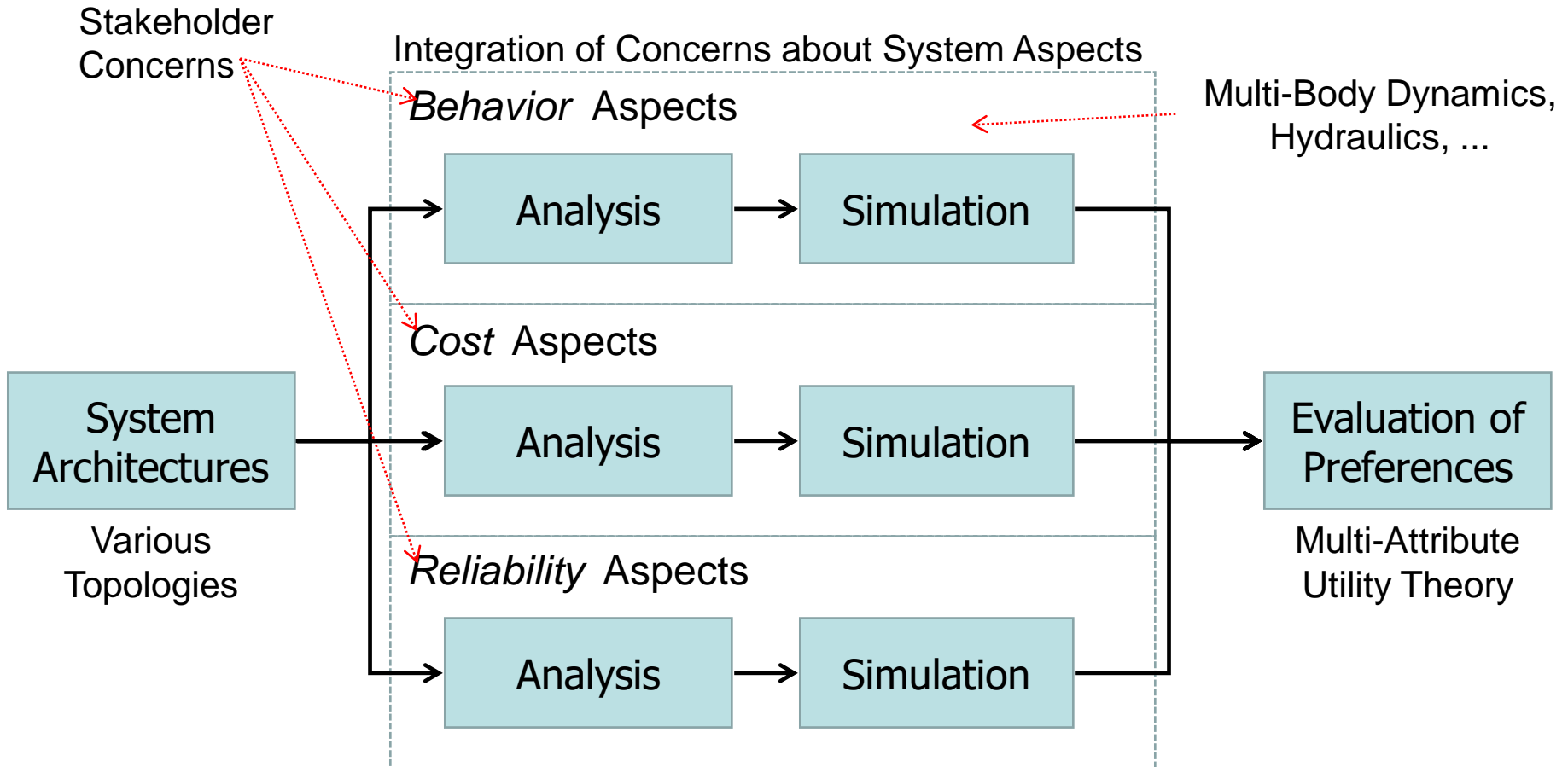


**Notes & Legend**

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# Excavator Analysis/Simulation Models

## *Problem Definition*

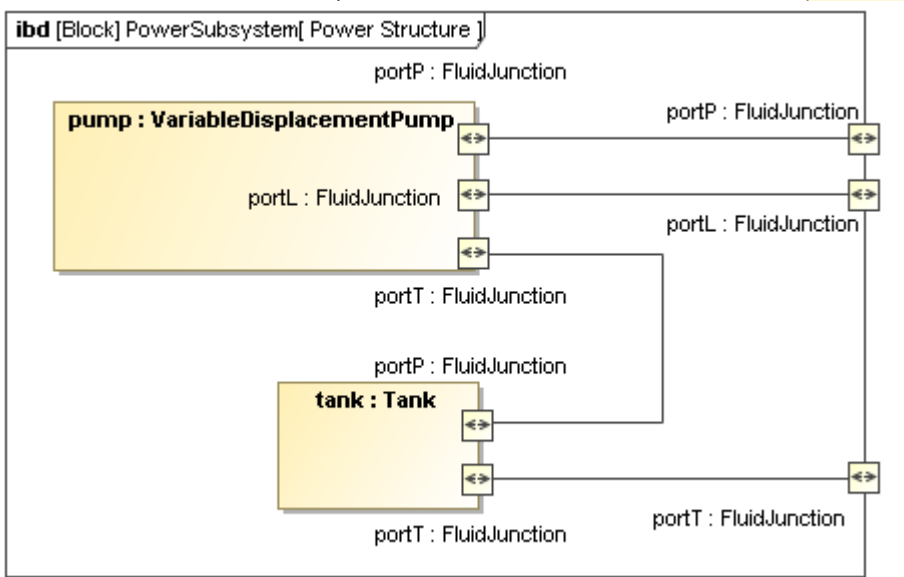
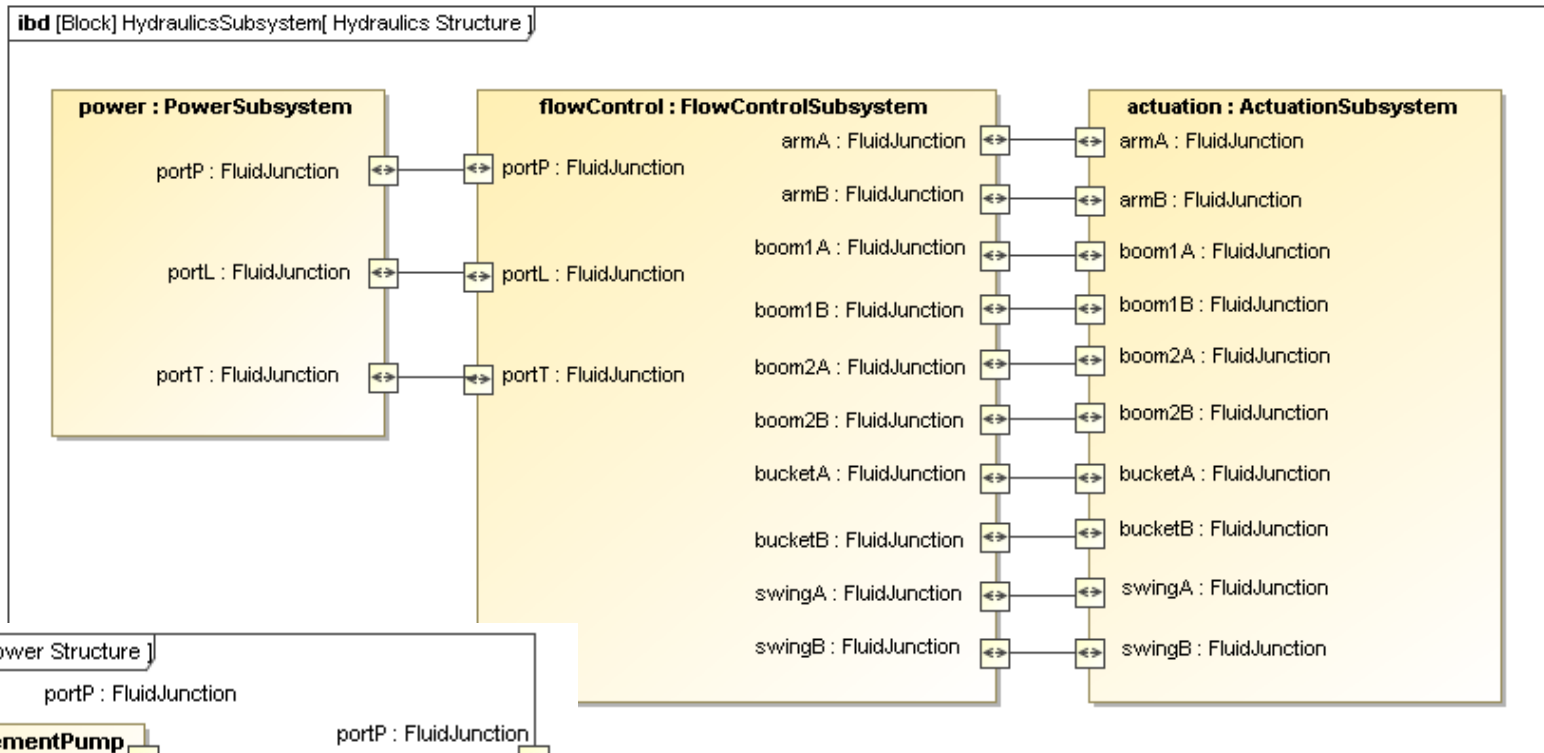


[Paredis et al. 2007]



# Excavator Hydraulics Subsystem

## Design Structure Models





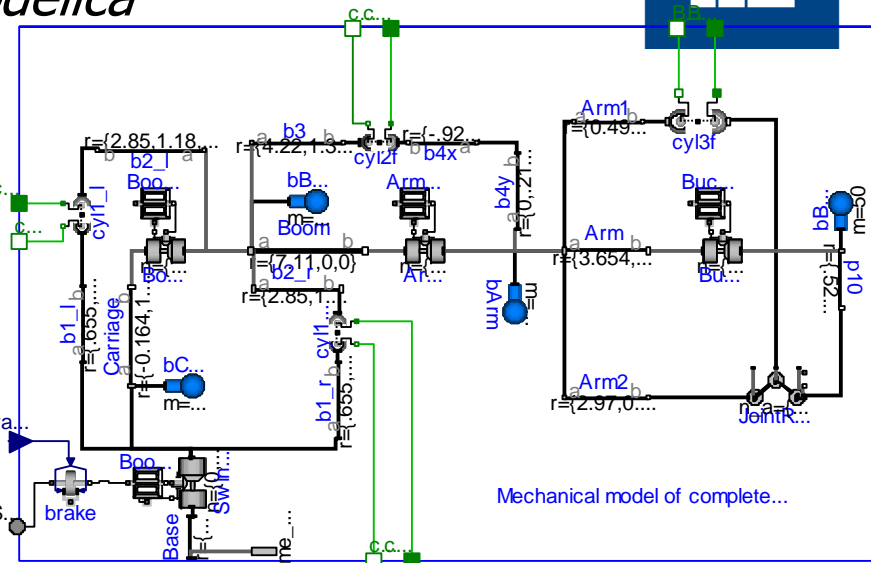
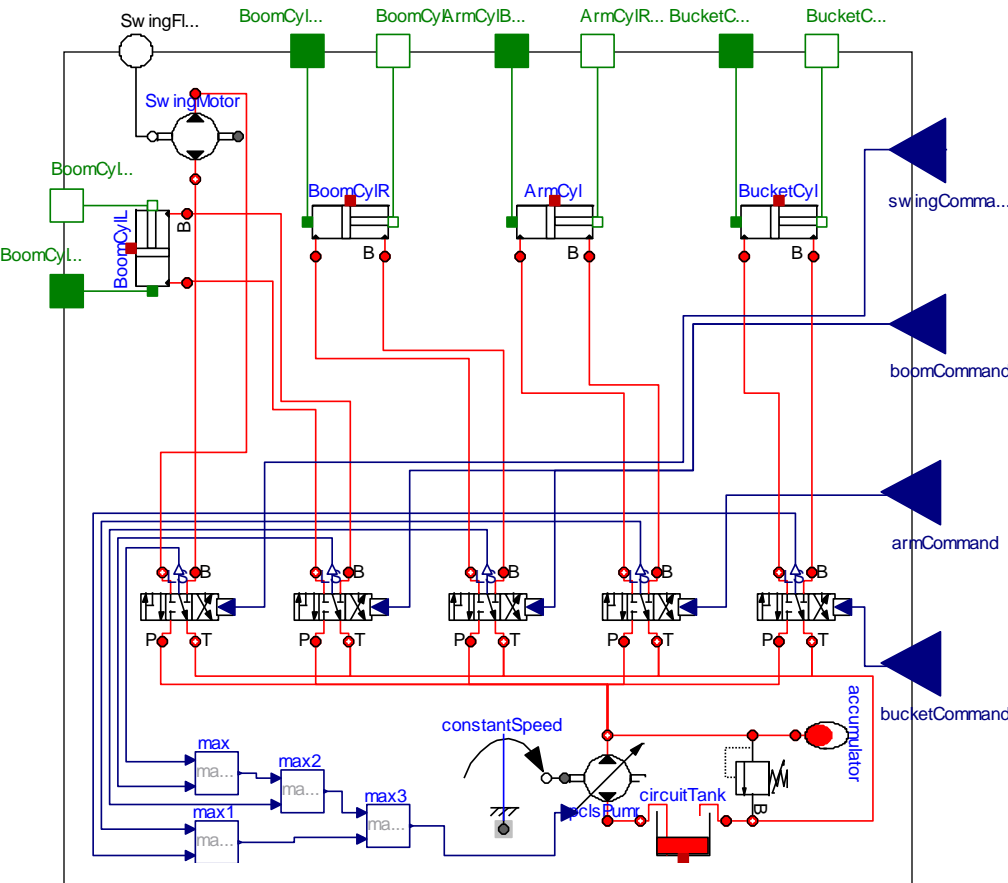


# Excavator Case Study

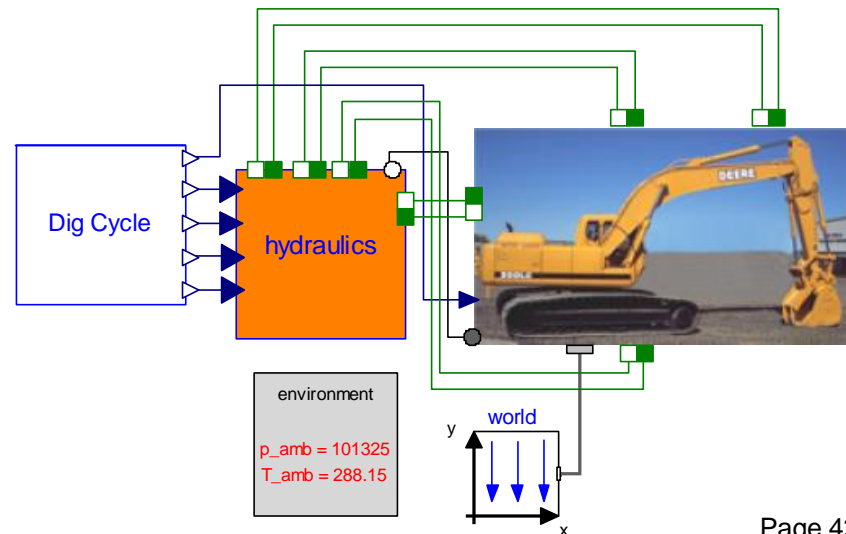
*Native Tool Models: Modelica*



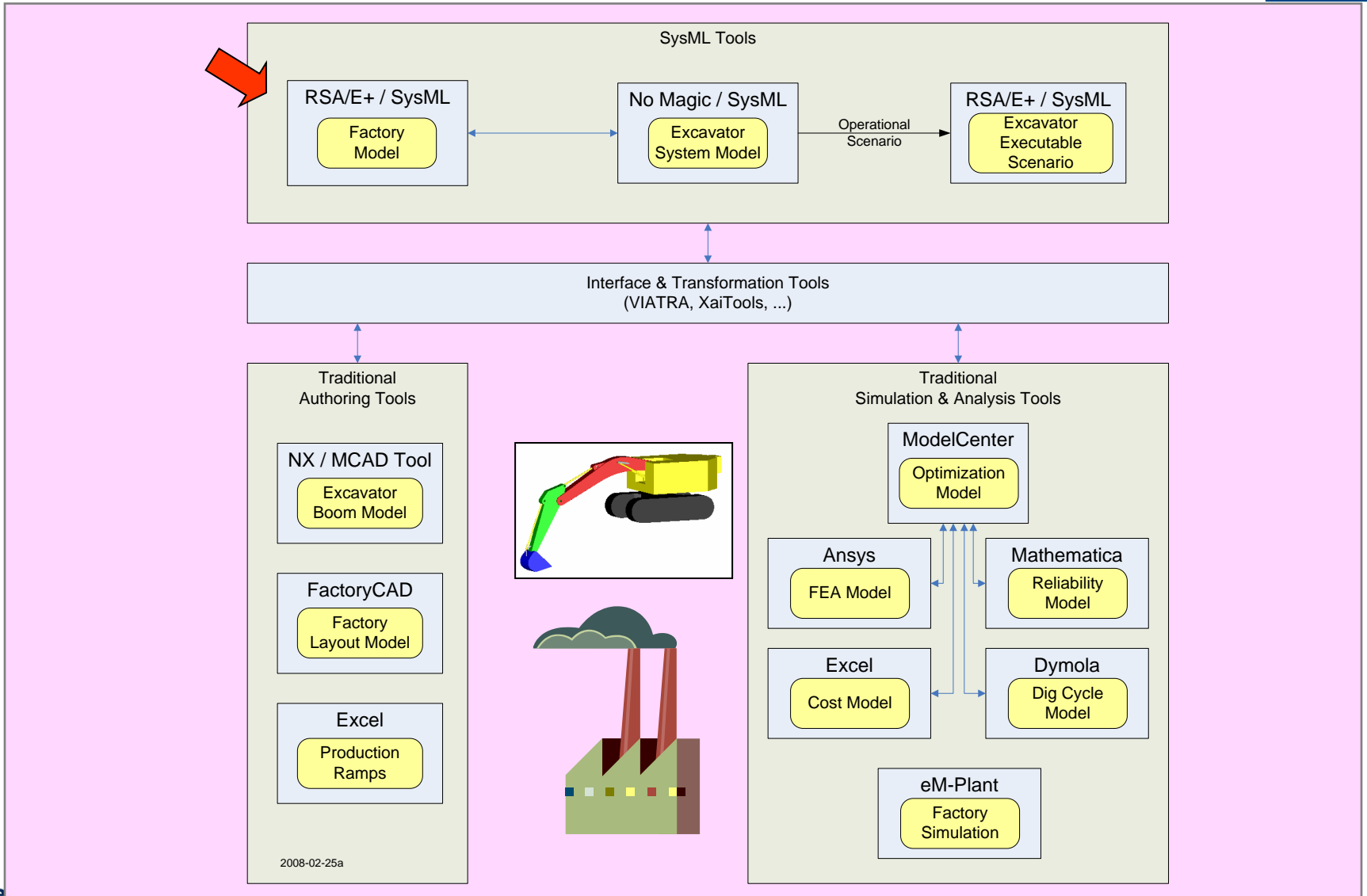
## Hydraulics Model



## Multi-Body System Dynamics Model (linkages, ...)



# GIT Testbed: Tools and Models



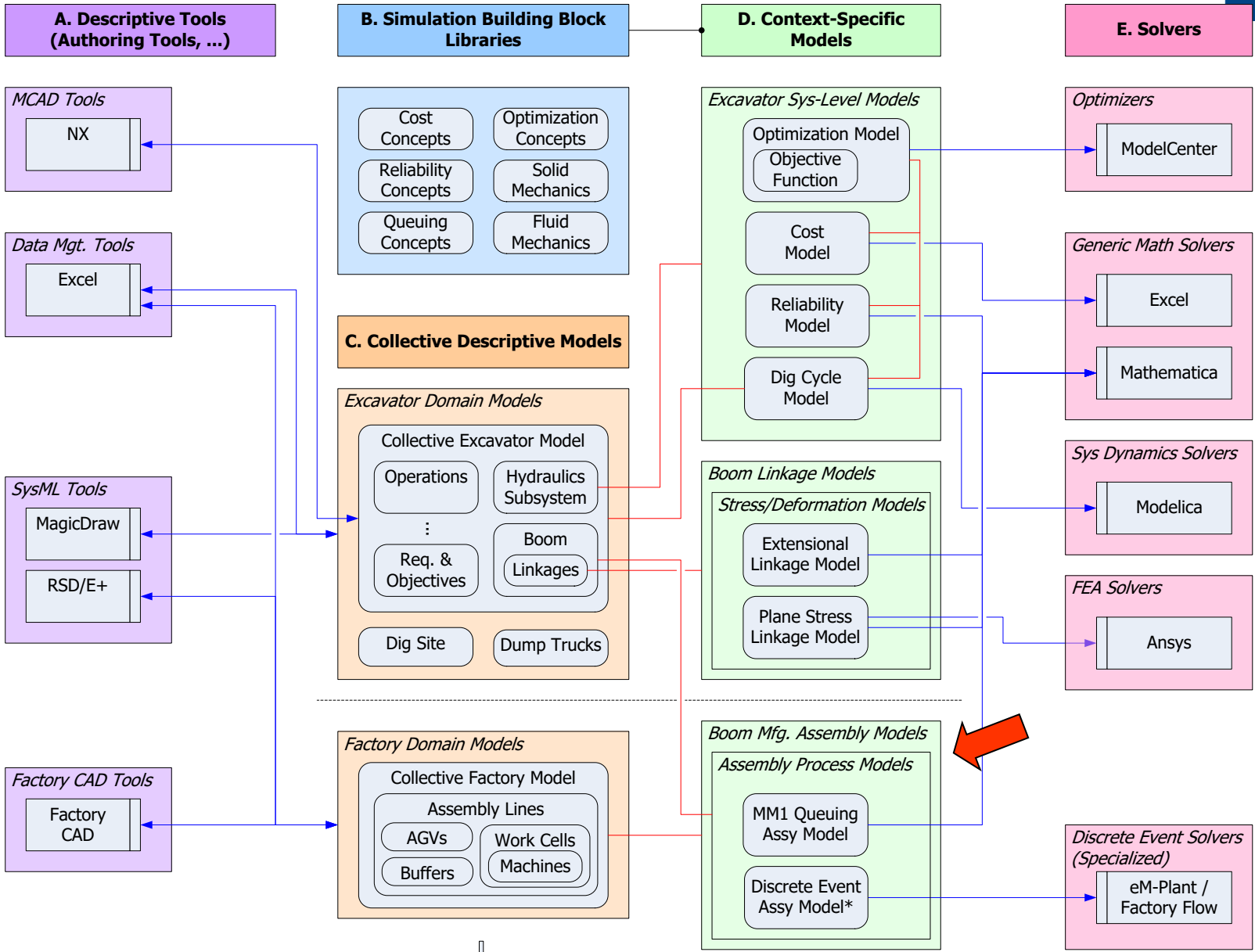
2008-02-25a

# Excavator Modeling & Simulation Environment

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2008-01-25  
\* This model is in a GIT prototype tool (with a schema based on its offline SysML model).

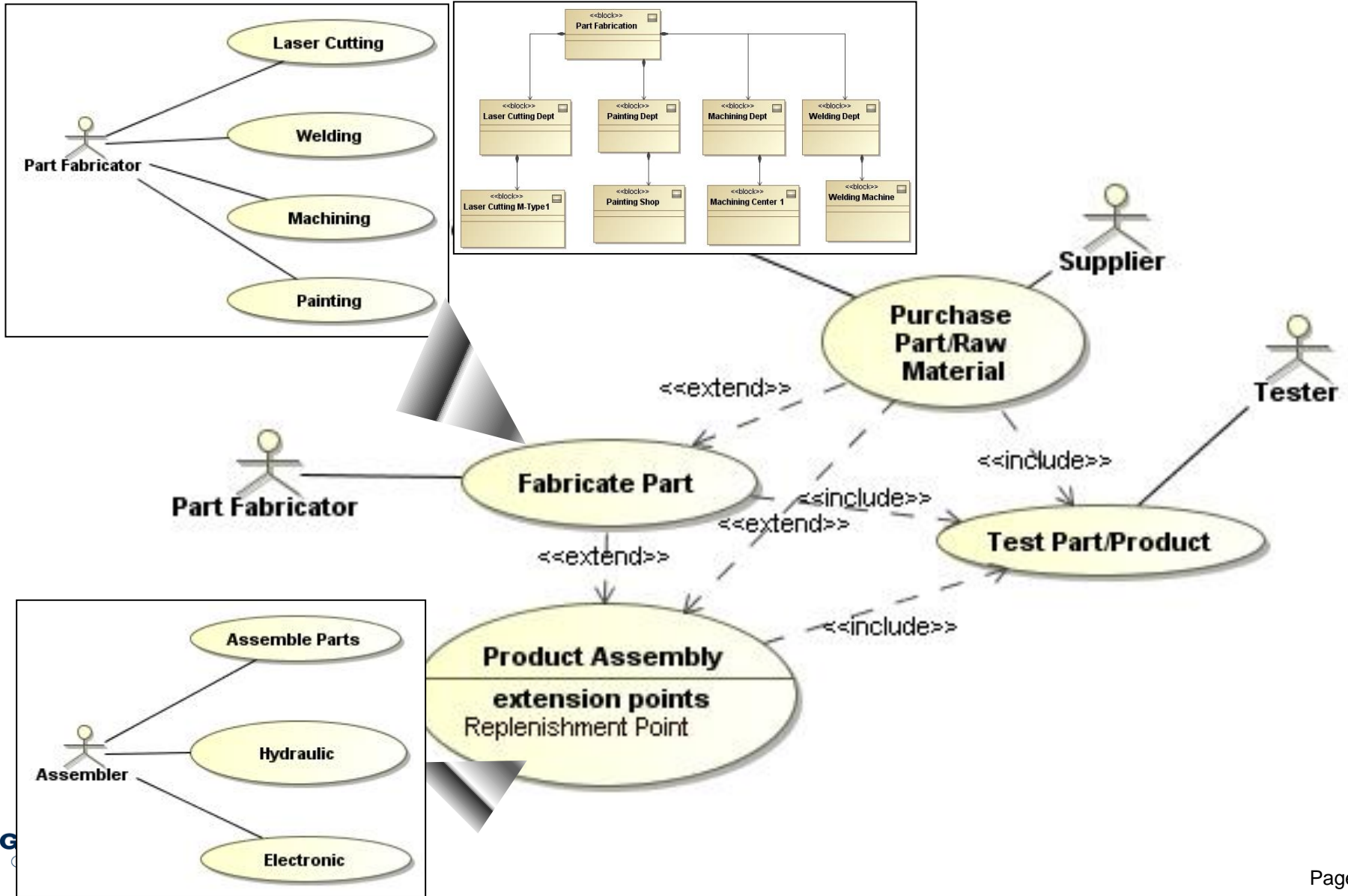


**Notes & Legend**

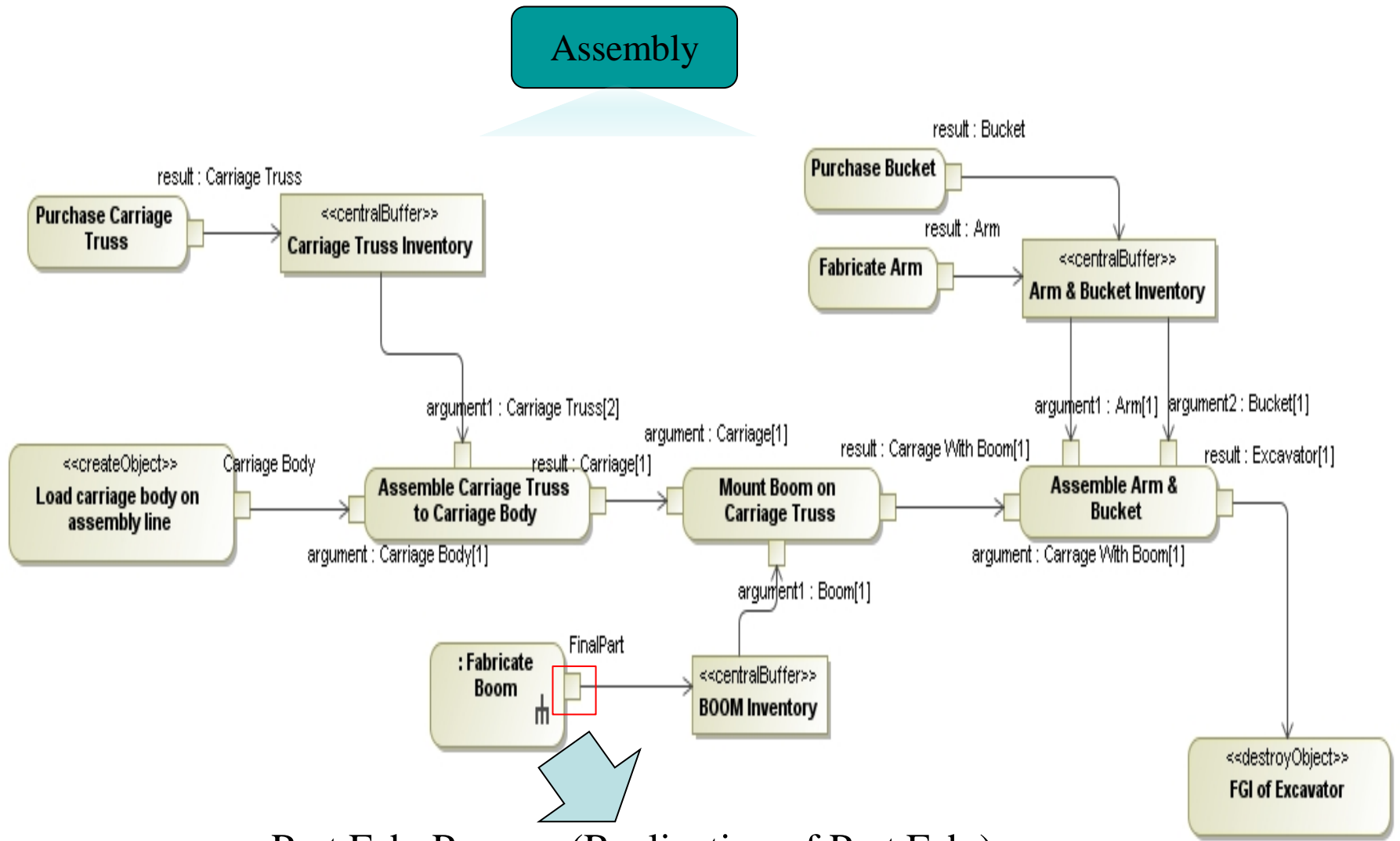
1) All models shown are SysML models unless otherwise noted.  
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 3) Infrastructure and middleware tools are also present (not shown)—e.g., PLM, CM, Parametric graph managers (XaiTools etc.), repositories, etc.

Tool interface (via XaiTools, etc.)  
— Parametric relationship  
● Composition relationship  
→ Native model relationship (via tool interface, stds, ...)

# Use Case Drives Function



# Activity Diagram Describes Process Plan

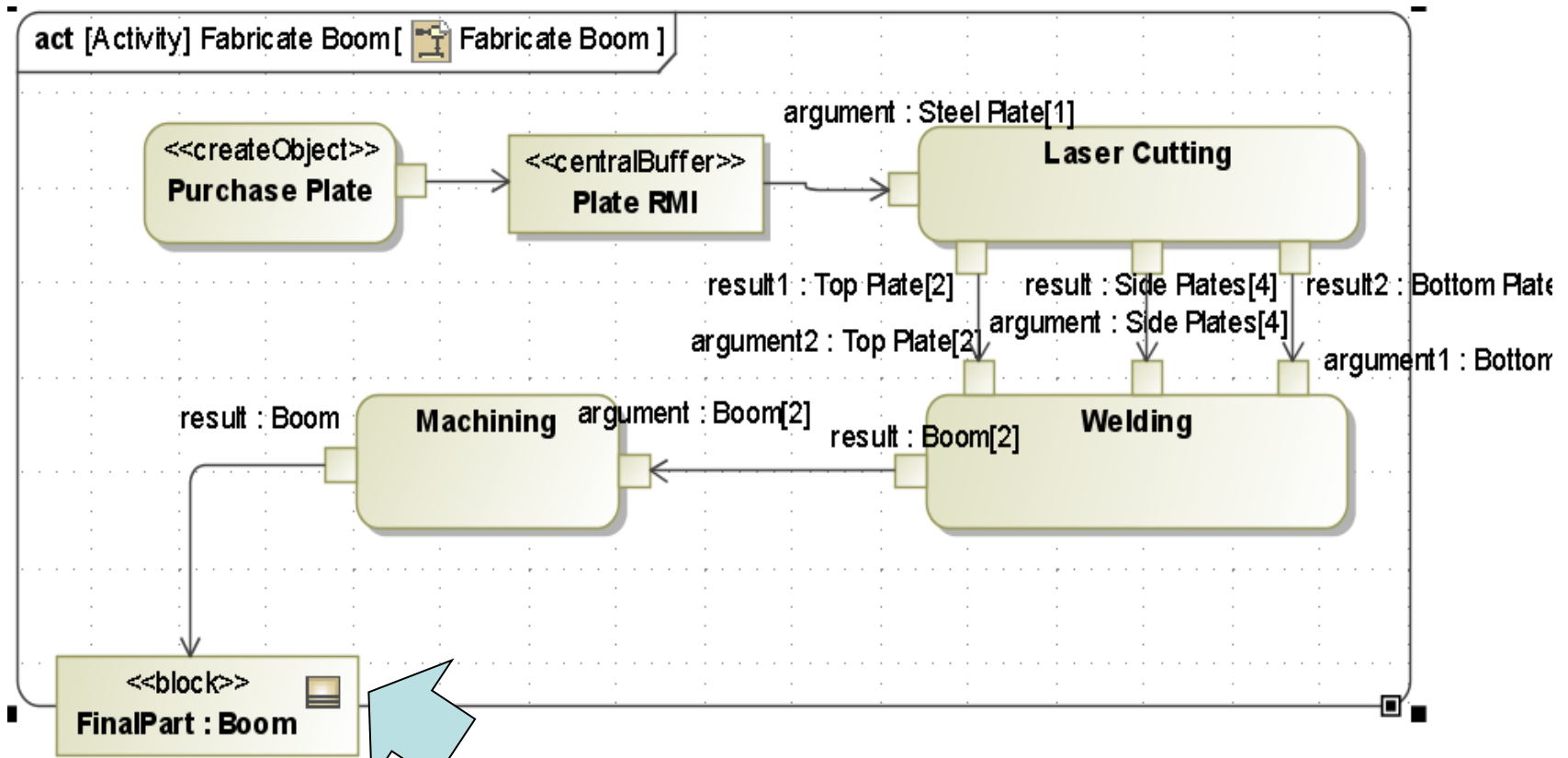


Part Fab. Process (Realization of Part Fab.)

# Elaborating Process Plan

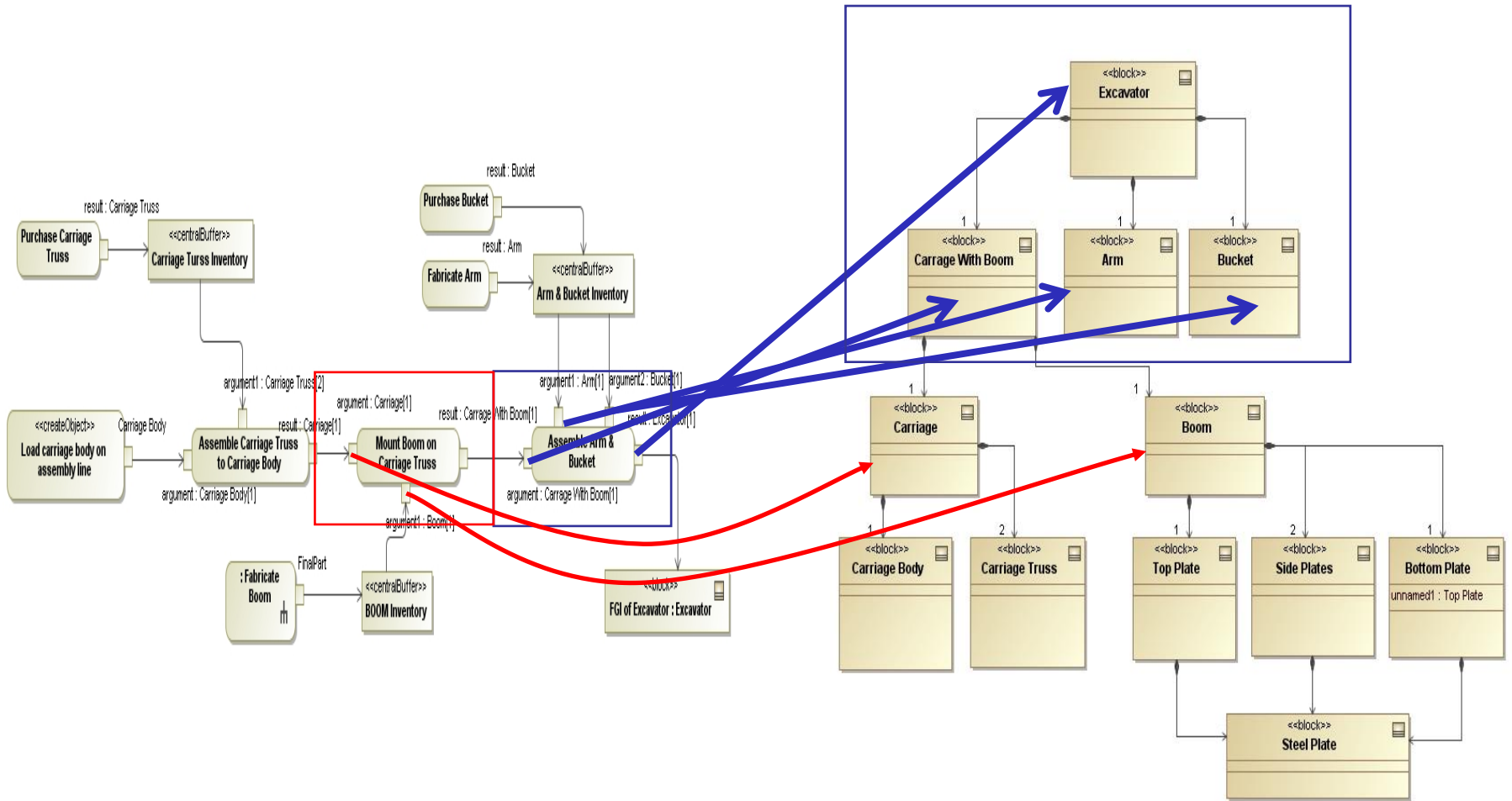


Fabricate

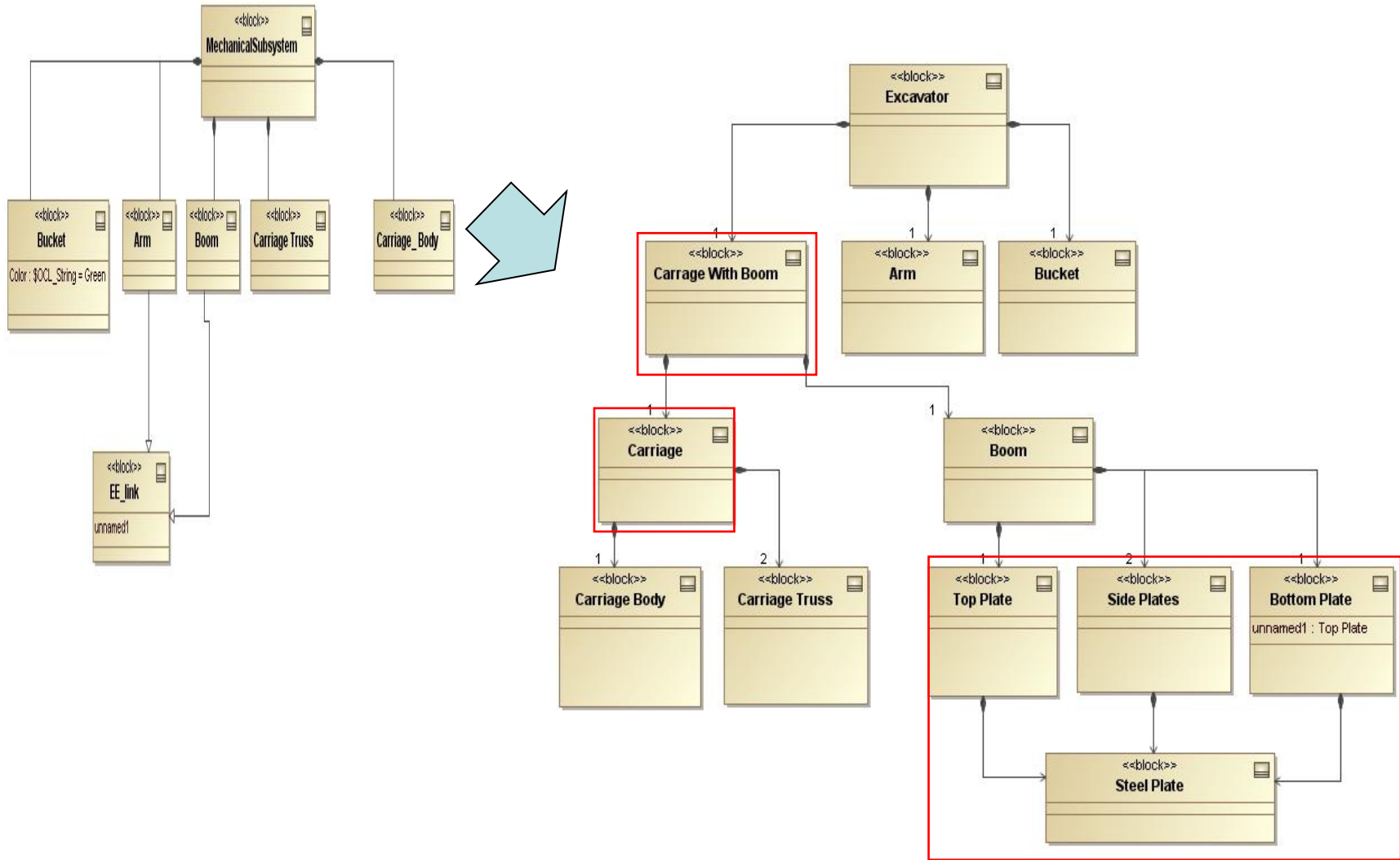


Output pin of upper level

# Process Defined MBOM



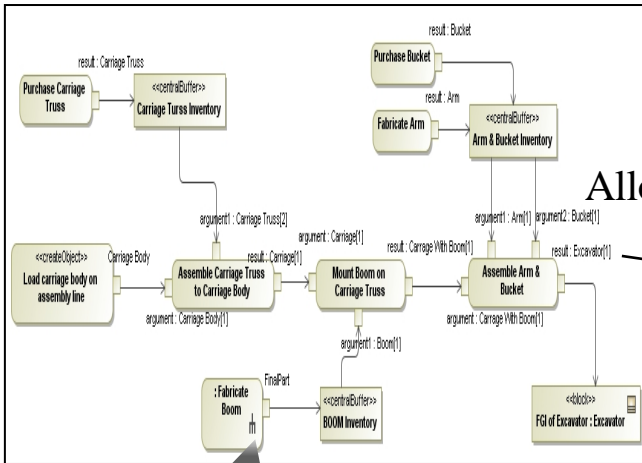
# From EBOM to MBOM



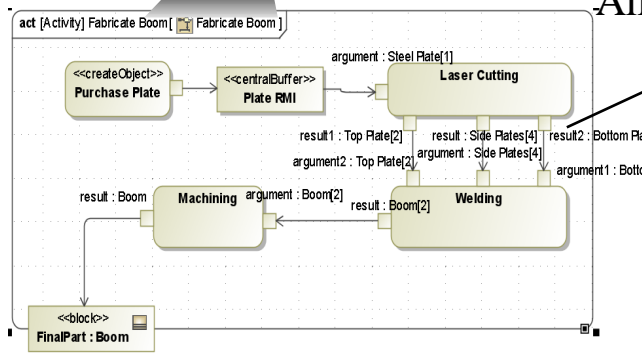




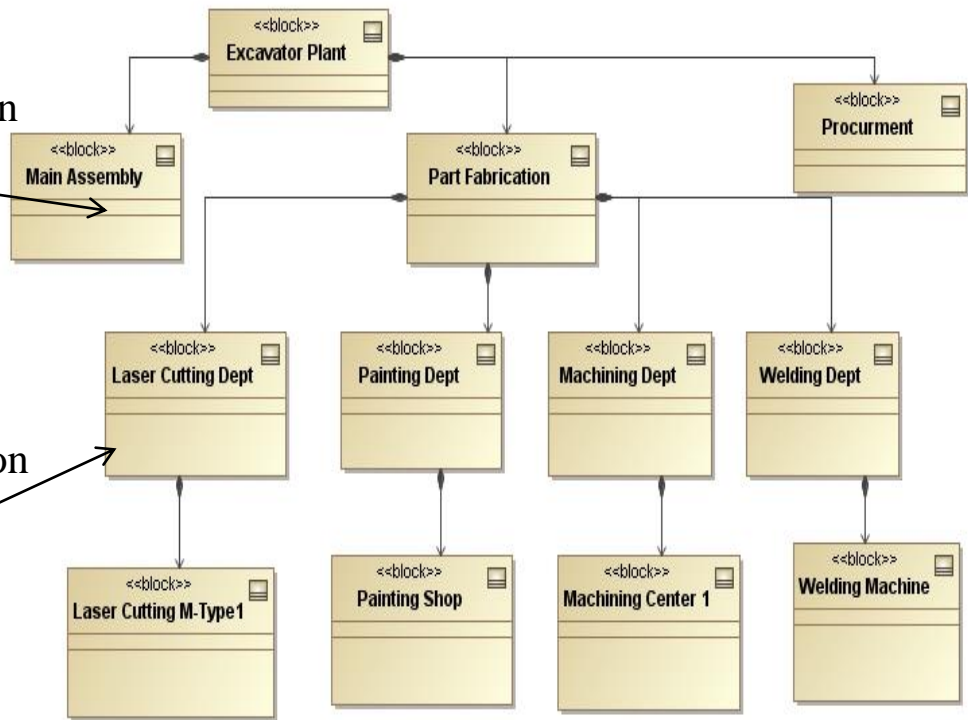
# Allocating resources



Allocation



Allocation

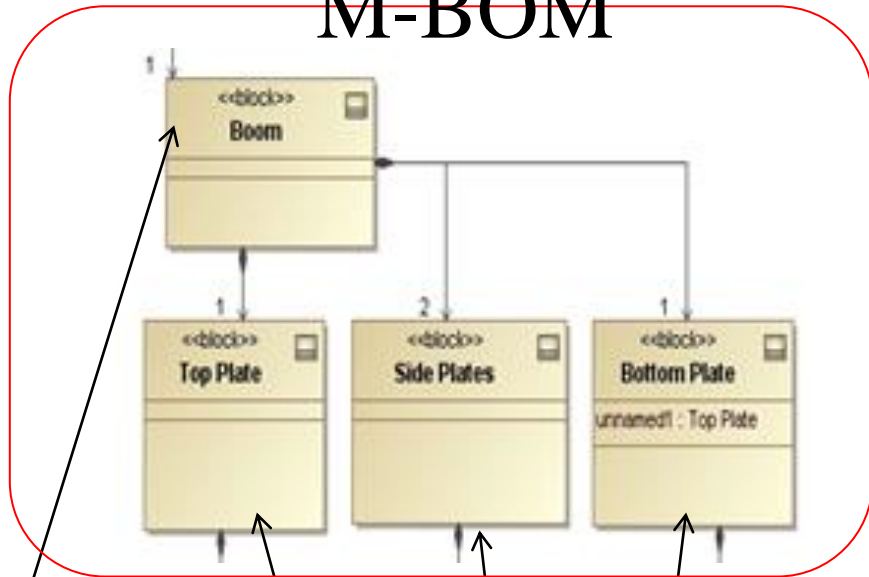


Capacity plan  
required  
(Parametric Dia.)

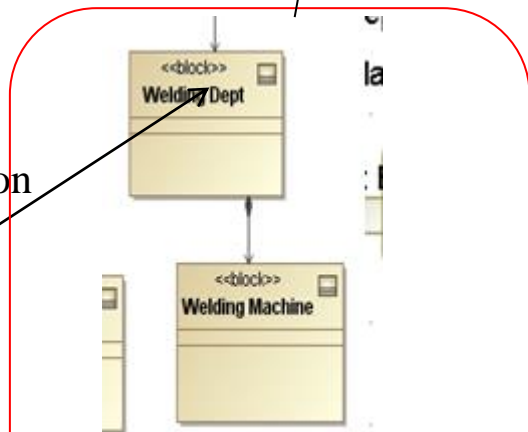
# Relations between realization components



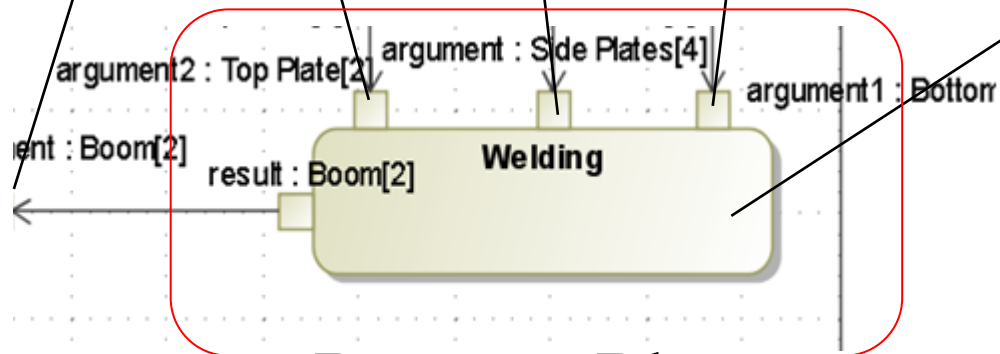
## M-BOM



Layout (FCAD)



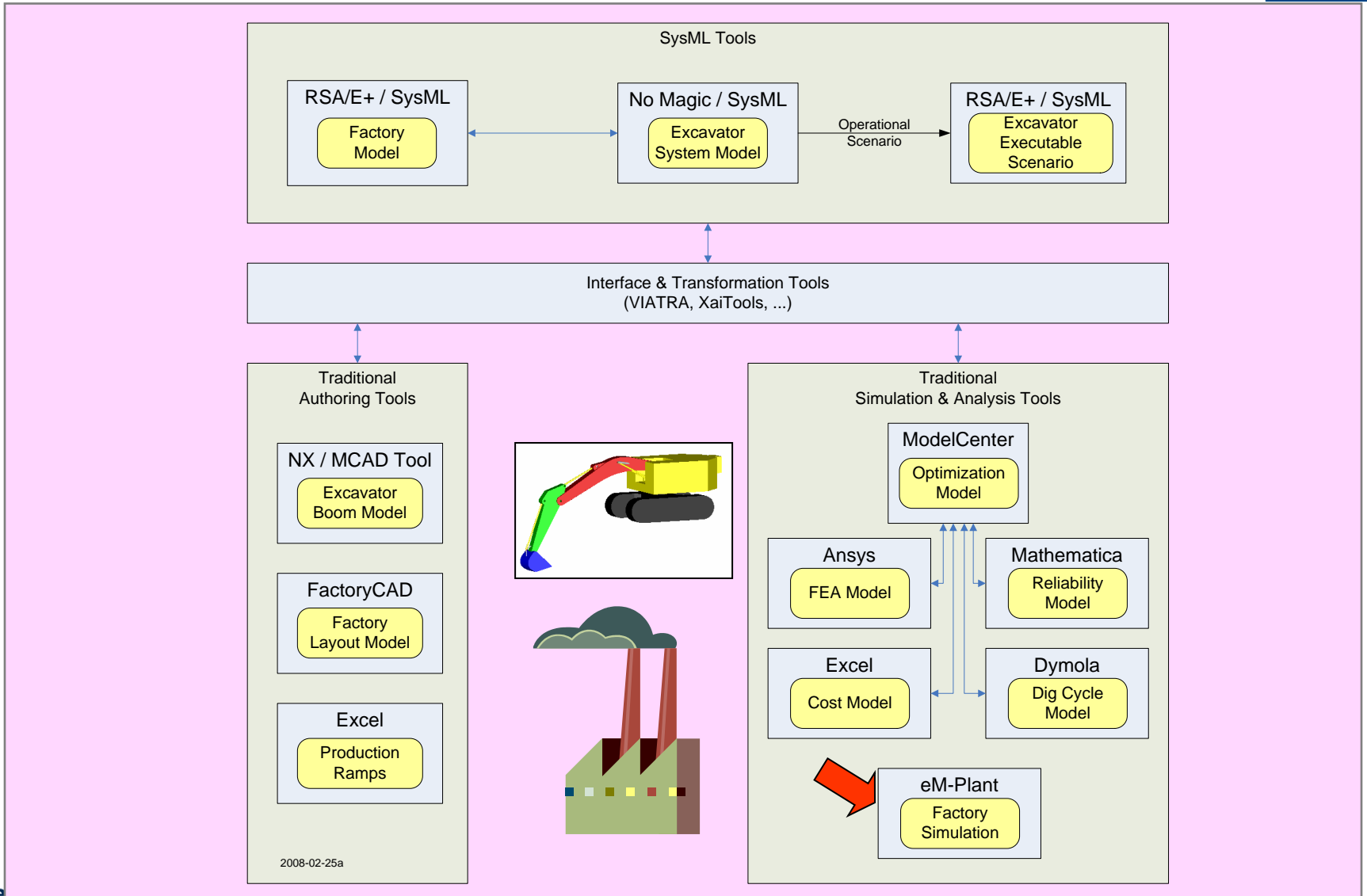
Allocation



## Process Plan

## Bill of Resource

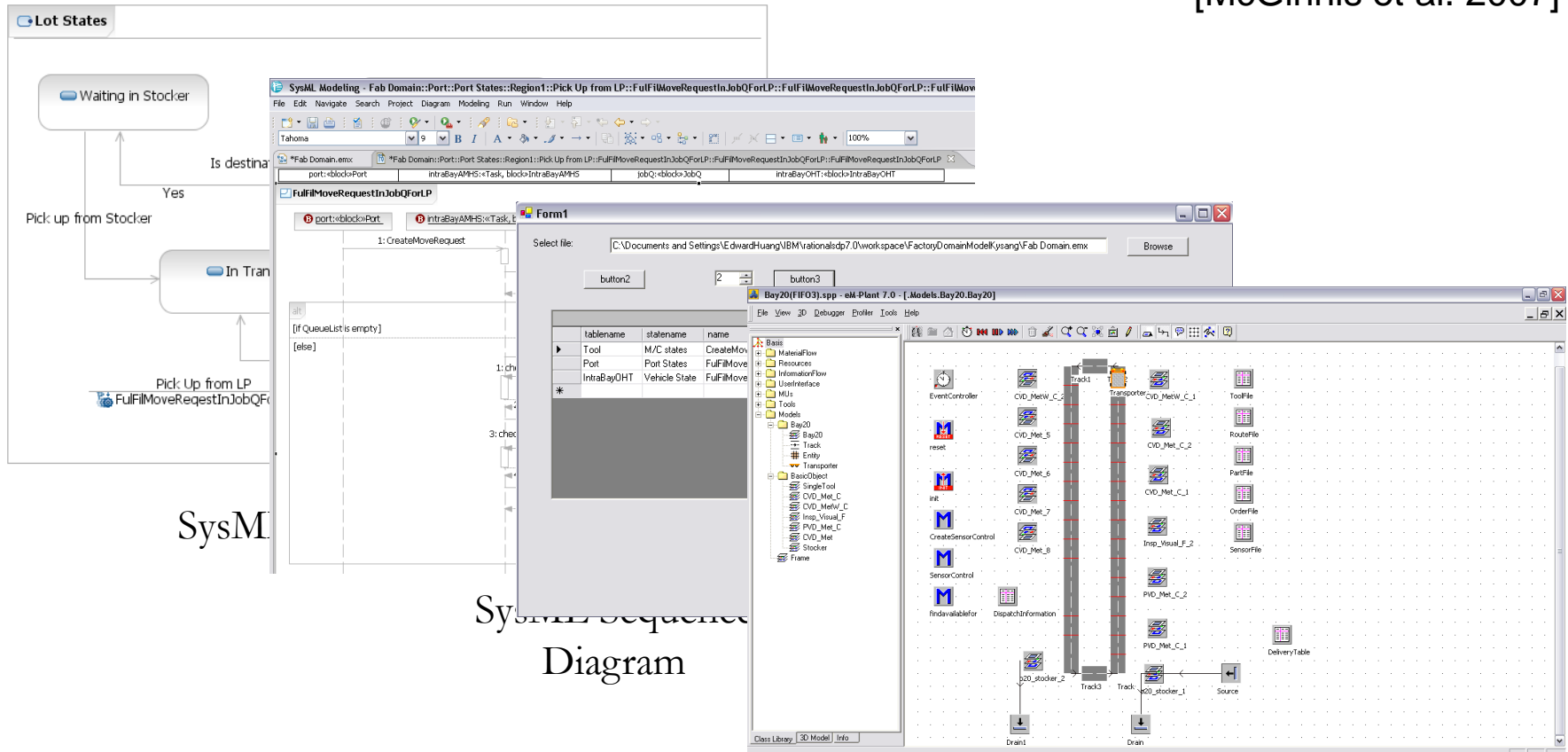
# GIT Testbed: Tools and Models



# Factory & Manufacturing Process Modeling & Simulation Using SysML



[McGinnis et al. 2007]



Discrete Event Simulation

# Result



- Design-to-Manufacturing Integration
  - Through the EBOM to MBOM transformation
- Design-to-Analysis Integration
  - Product models to product simulation
  - Factory model to factory simulation

# Implications for IE



- New paradigm for factory design and manufacturing planning
- New set of tools: computer aided IE
- New set of opportunities for IE tool research and development



Questions/Comments?

# SysML-Related Efforts at Georgia Tech



- SysML Focus Area web page
  - <http://www.pslm.gatech.edu/topics/sysml/>
  - Includes links to publications, applications, projects, examples, etc.
- Selected projects
  - Deere: System dynamics (fluid power, ...)
  - Lockheed: System design & analysis integration
  - NASA: Enabling technology (SysML, ...)
  - NIST: Design-analysis interoperability (DAI)
  - TRW Automotive: DAI/FEA (steering wheel systems ... )