Model-Based SE Using SysML
Part 2: Integrating Manufacturing Design and Simulation

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www.pslm.gatech.edu
• SysML-related projects:
  – Deere, Lockheed, Boeing, NASA, NIST, TRW Automotive, ...
• Other efforts based at GIT:
  – Vendor collaboration (tool licenses, support, ...)
  – **Keck Virtual Factory Lab**
  – SysML course development
    • For Professional Masters in SE program, continuing ed. short course, ...
    – **ASDL in AE**
    – **Tennenbaum Institute for Enterprise Transformation**
• Consortia & other GIT involvements:
  – OMG (SysML, ...) 
  – PDES Inc. (MBE, APs 210, 233, ...)

**www.pslm.gatech.edu**
Excavator Modeling & Simulation Testbed

Tool Categories View

SysML Tools
- RSA/E+ / SysML
  - Factory Model
- No Magic / SysML
  - Excavator System Model
- RSA/E+ / SysML
  - Excavator Executable Scenario

Interface & Transformation Tools
(VIATRA, XaiTools, ...)

Traditional Descriptive Tools
- NX / MCAD Tool
  - Excavator Boom Model
- FactoryCAD
  - Factory Layout Model
- Excel
  - Production Ramps

Traditional Simulation & Analysis Tools
- ModelCenter
  - Optimization Model
  - Ansys
    - FEA Model
  - Mathematica
    - Reliability Model
  - Excel
    - Cost Model
  - Dymola
    - Dig Cycle Model
  - eM-Plant
    - Factory Simulation

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Model-Centric Framework

Produce, Merge, Enrich, Consume

http://eislab.gatech.edu/pubs/journals/2004-jcise-peak/ (where “collective product model” = “federated system model”)

Producer Tools (Primary Authoring)

Enricher Tools (Secondary Authoring)

Consumer Tools (e.g., Solvers)

Federated System Model

Meta-Building Blocks:
- Information models & meta-models
  - International standards
  - Industry specs
  - Corporate standards
  - Local customizations
- Modeling technologies:
  - Express, UML, SysML, COBs, OWL, XML, …
My focus today:

• What does it mean “to integrate manufacturing with design?”
• What does it mean “to integrate manufacturing system design with manufacturing system simulation?”
• How can we make these two things happen?
Integrating Manufacturing and Design

Design Target

Design Phase

Conceptual
- Material
- Weight
- Architecture

Preliminary
- Structure
- Skin
- Shapes
- Basic Geometry

Detailed
- All features
Integrating Manufacturing and Design

Design Target

Design Phase

Conceptual
- Material
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Preliminary
- Structure
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- Basic Geometry

Detailed
- All features

Interface

?  

Interface

?  

Interface

?  

Interface
Product Models in CAD
Product Model
(E-BOM vs M-BOM)
Manufacturing Context
Design to Manufacturing Integration

• EBOM to MBOM Transformation
• Or “EBOM to WBS”
• More than “interoperability” or “converting a file format”; “how” based on “what”
  – Sourcing (=> logistics, cost, schedule …)
  – Resource organization/assignment (=> mfg cost)
  – Inventory/WIP positioning (=> cycle time …)
R&D Strategy

• Conform factory design to product design
  – Functional design
  – Detailed design
• Recognize process planning as the “design to manufacturing” bridge
• Manufacturing as part of a federated “enterprise” model
Factory Design Capabilities
Design Data: EBOM + MCAD
Functional Design for Manufacturing Process—SysML Use Cases
Factory Functional Design

- Excavator Plant
  - Main Product Assembly
  - Module Assembly
  - Part Fabrication
    - Purchasing Department
    - Test
Function Detailed Design
Resource Model & Layout Model

Tool Instance Data in Excel

<table>
<thead>
<tr>
<th>Name</th>
<th>Tooltype</th>
<th>x</th>
<th>y</th>
<th>OperationType</th>
<th>Cutting Speed</th>
<th>LoadingTime</th>
<th>UnloadingTime</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bending_Machine1</td>
<td>BendingMachine</td>
<td>2000</td>
<td>500</td>
<td>Single</td>
<td></td>
<td>100</td>
<td>50</td>
</tr>
<tr>
<td>Laser_Cutter1</td>
<td>LaserCutter</td>
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<td>1000</td>
<td>Cut Shape</td>
<td>4</td>
<td>300</td>
<td>200</td>
</tr>
<tr>
<td>Welding_Machine1</td>
<td>WeldingMachine</td>
<td>3000</td>
<td>1500</td>
<td>Assembly</td>
<td></td>
<td>100</td>
<td>100</td>
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Bill of Resource in SysML

Factory Layout in FactoryCAD (AutoCAD)
Layout Using F-CAD Library from SysML

FactoryCAD Library

Select/Place

Layout Drawing
Capturing Layout Information

Layout Drawing -> Extract SDX -> Xpath Parser -> Study DB

Database
Observations

• Factory design is driven by:
  – What
  – How much
  – When
  – Where

• So how do we integrate those issues?

• Use SysML Activity Diagrams to capture how we intend to use manufacturing resources to create the product
Process Planning Model
Detailed Process Planning
Operation Allocation
Manufacturing Process Model
Activity Diagram to MBOM Transformation

Automated Transformation
BOM Transformation using Moflon

Meta-model level based on MOF (Modeling)

Activity Metamodel

BOM Transformation rule

Correspondence + SD described by MOF

BDD Metamodell

Integrator based on JMI level (Execution)

Source model

Transformation Rule

Target model

JMI

JMI

JMI

MD Adapter

XMI Adapter

Link information

Data Repository

Magic Draw

MD Adapter

XMI Adapter

Magic Draw

Source model

Transformation Rule

Target model

JMI

JMI

JMI

MD Adapter

XMI Adapter

Link information

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Magic Draw

MD Adapter

XMI Adapter

Magic Draw
Manufacturing Model Interdependencies
Summary
Federated Model Interfaces

**Tools**
- Excel: Vendor Tool info
  - C#

**Library**
- E+
  - C#

**Instance**
- Excel
  - C# 
  - MD BDD: Factory Organization
- FactoryCAD Library
  - MD BDD: E-BOM

**Process Plan**
- MD Activity Diagram
  - MD BDD

**M-BOM**
- Moflon

**Access Tables**
- eM-Plant script
  - eM-Plant

**Simulation**
Conclusion

- SysML and formal models enable a formal interoperability between product design models and factory design and process planning models.
- Not clear yet how to make the connection the other way…future R&D
Simulation Capabilities
Factory simulation is not directly accessible by factory engineers.
Observations

• Factory engineers must “author” requirements
• Simulationists must determine a process for converting “requirements” into “simulation code”
• We can automate what simulationists do if it conforms to a repeatable (learnable) pattern.
Proposed Factory Simulation Framework

On-Line

User

COTS Authoring Tools

Descriptive Model Libraries

Model Translator

Analytic Model Libraries

COTS Solver

COTS Formal Analytic Model Instance

Formal Descriptive Model Instance

Results

Georgia Institute of Technology
Proposed Factory Simulation Framework

Off-Line

Descriptive Model Libraries

Model Translator

Analytic Model Libraries

User

Modeler
Proposed Factory Simulation Framework

**On-Line**
- User
- COTS Authoring Tools
- Formal Descriptive Model Instance
  - COTS Solver
  - Results

**Off-Line**
- Modeler
- Descriptive Model Libraries
- Model Translator
- Analytic Model Libraries

- User
Factory Model Concept

System Structure

System Behavior

Block

State 1

State 2

action1

action2

action3

State 1

State 2
Factory Structure

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Bill of Resource in SysML

Factory Layout in FactoryCAD (AutoCAD)
Behavior Modeling

Entity

- In Process
- Effect: Job complete

Lot

Control System

Entity-Job Complete

Notify

Dispatch

Entity

- Waiting in the output buffer
- Dispatch event

Lot

Control System

Notify

Dispatch

Entity

- Dispatching

Lot

Control System

Notify

Dispatch

Entity

- Loading in the input buffer
- In transit

Lot

Control System

Notify

Dispatch

Entity

- Idle

Lot

Control System

Notify

Dispatch

Entity

- In Process
- Job Finish Event

Lot

Control System

Notify

Dispatch

Entity

- Waiting in the output buffer
- Dispatch event

Lot

Control System

Notify

Dispatch

Entity

- Dispatching

Lot

Control System

Notify

Dispatch
Behavior Modeling - state machine diagram
Behavior Modeling-Sequence diagram example

```
interaction [ ]

<<Block>>
: Buffer_BucketSideThickPlate

1: checknumMu();

<<Block>>
: Pattern2

2: checkamount();

<<Block>>
: Buffer_Pattern2

3: ReleasePattern2()

opt
[if nummu + 3 * numpattern2 < 15 then]

2: checkamount();
```

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Simulation Generator--Structure
Simulation Generator--Behavior
Implementation Challenges

• NOT structure—NIST CMSD is one start toward a practical standard for structure

• Modeling Control!
  – State machine/Sequence Diagram?
  – Activity Diagram?
  – Executable UML?
  – What’s the fundamental conceptual model?
    • Moore machine
    • Mealy machine
    • DEVS
    • Other?
If you want to play this game

• Formal languages
  – *SysML is our bet*

• Model transformation
  – *MOFLON? QVT? We’re not completely sold…*

• Implicit/Explicit paradox

• Domain specific languages
  – *Profiles of SysML*
Conclusion

• SysML and formal models (potentially) enable an unprecedented integration of manufacturing system “description” and manufacturing system simulation (like the MCAD and ECAD domains now enjoy)

• Rationalization of factory control remains the fundamental challenge—how can we reconcile the complexity of real factory control with the need to create (in finite time and finite cost) useful factory simulations?
Main Questions Addressed by Project

- **Process:** How do we include engineering analysis tools in the MBSE process?
- **Representation:** How do we represent engineering analysis models in SysML?
- **Execution:** How do we integrate engineering analysis tools & models with SysML tools & models?