

Presentation at Annual SERC Research Review

Nov 10, 2010

College Park, Maryland

v1.1

Overview of Systems Engineering Research at Georgia Tech

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(presenters)

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(other main contributors)

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Ender, et al.
 - Aerospace Systems Design Lab (ASDL)
Mavris, et al.
 - Model-Based SE Center (MBSEC)
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- Summary

Georgia Tech Fun Facts



1885

1903

1948

1996

Mascots

Founded
in
Atlanta

Faculty

5 Professors
5 Shop Supervisors

Students

129 undergrads in
Mechanical
Engineering



First full-time
football coach

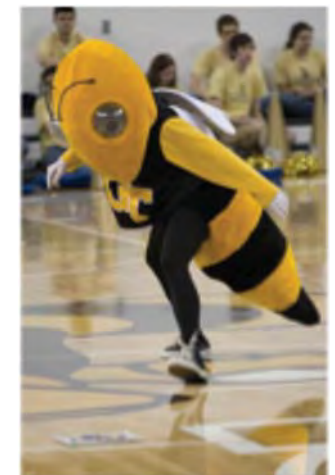
*John
Heisman*



Renamed
*Georgia
Institute of
Technology*



Served as
Olympic
Village for
10,000+
athletes/staff



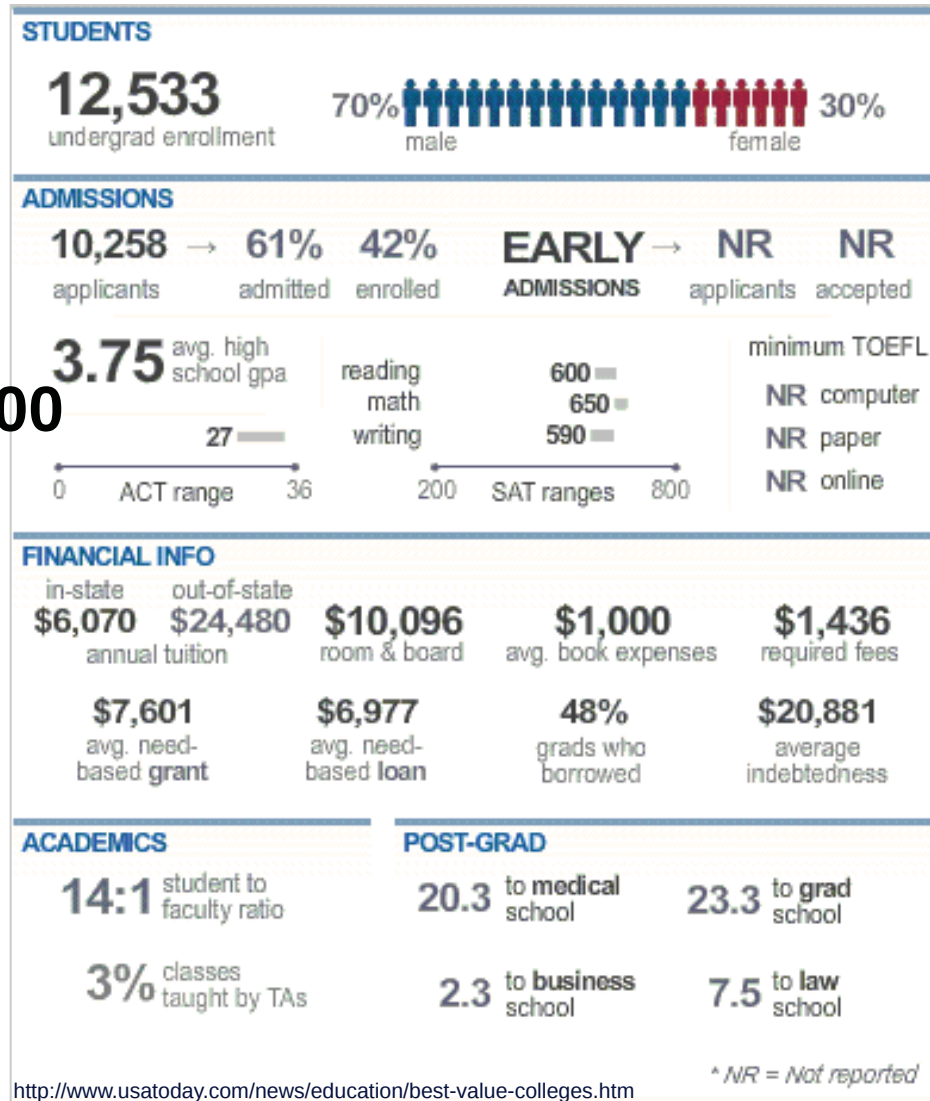
Georgia Tech Statistics

Students

- undergrad: ~12,000
 - grad: ~8,000
 total: ~20,000

engineering: ~11,000

The Princeton Review 100 Best Value Colleges for 2010



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Professional Masters in Applied Systems Engineering

www.pmase.gatech.edu

The degree program:

- Targeted to working professionals (5+ years experience)
- Convenient format combining distance learning and onsite interactions
- An applied degree taught from an enterprise view
- Relevant tools for solving real world problems



The PMASE Curriculum

Core Curriculum

ASE 6001: Fund in Modern SE

ASE 6002: Sys Design & Analysis

ASE 6003: M&S for SE

ASE 6004: Leading SE Teams

ASE 60X5: Advanced Topics in SE

- SysML
- HSI

ASE 6006: SE Lab

SE Processes & Techniques

Integrated SE Mgt

SE Tools, Standards, Languages

Domain Specific Engineering

Complex Systems

Complex Systems Curriculum

ASE 61X1: Domain Elective in Synthesis & Analysis

- Vehicles
- Sensors
- Info Systems
- HSI

ASE 6102: SOS & Architectures

ASE 6103: Lifecycle & Integration

ASE 6104: Complex Systems Capstone

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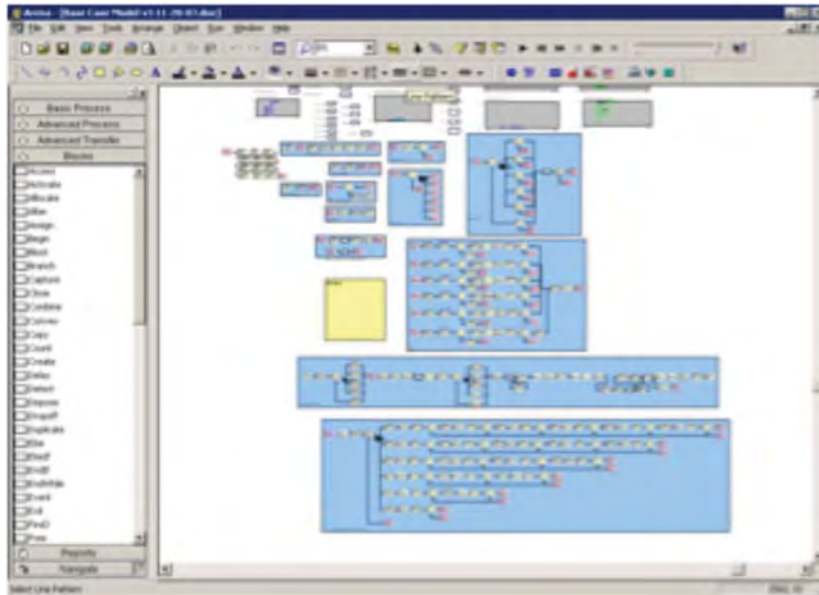
See also our work
in RT16 and RT25





- Interdisciplinary research
- Understand and enable fundamental change of private and public sector enterprises
- Defense acquisition
- Services
- Energy
- Enterprise integration
- Global manufacturing
- Health care

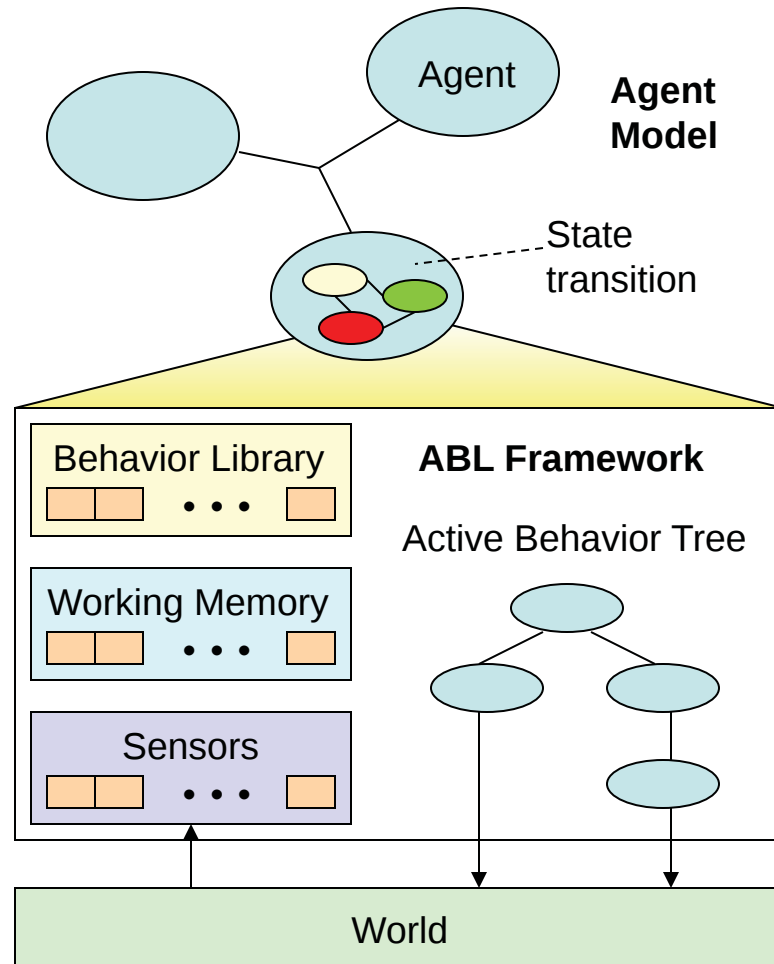
Defense Acquisition



Weapons systems progress through the acquisition lifecycle, including sustainment. The impacts on cost, schedule performance and risk are compiled.

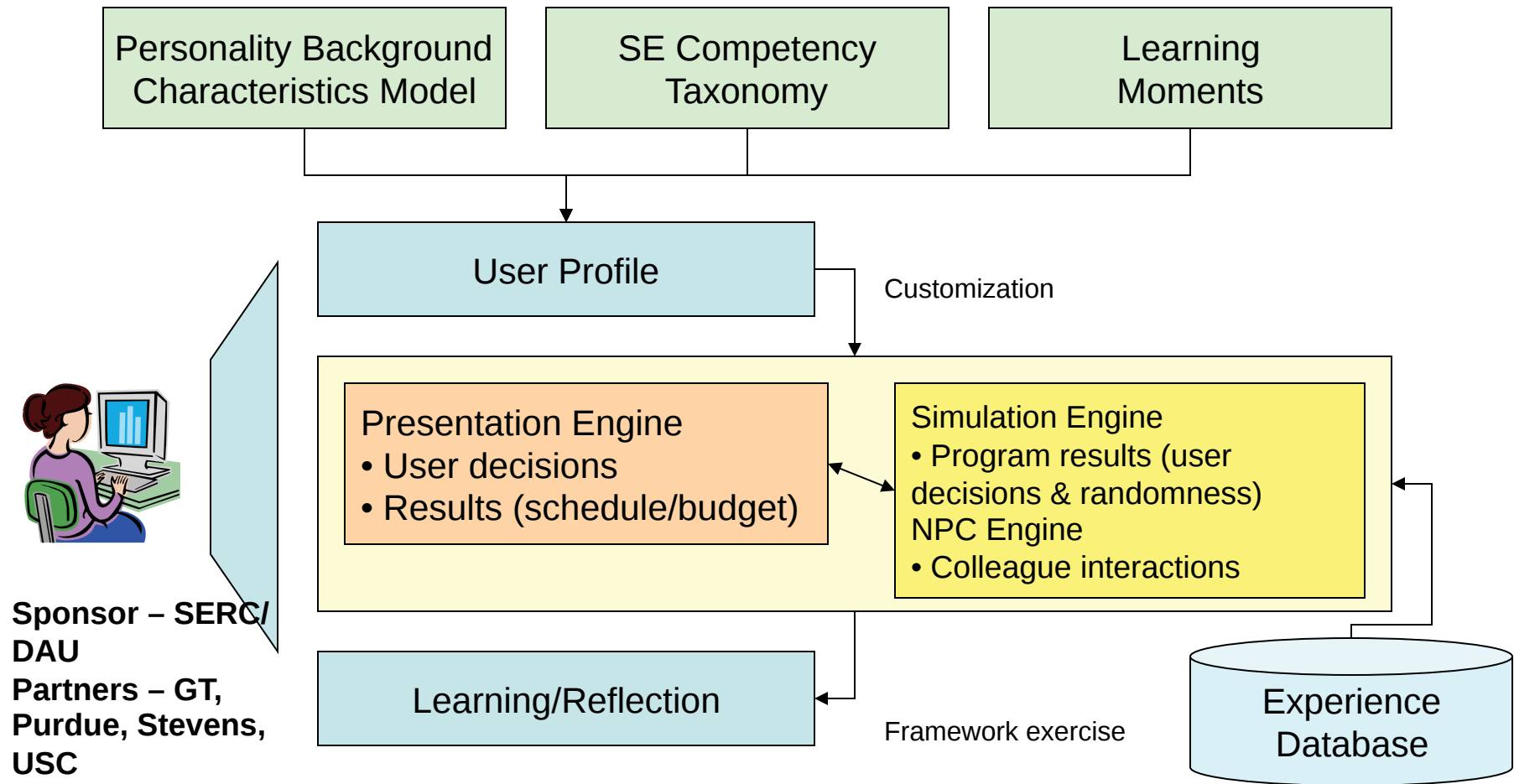
- Goal – investigate relationships between evolutionary acquisition, system modularity and production level
- Findings
 - Evolutionary acquisition tends to reduce program costs but increase enterprise costs
 - Modularity tends to increase development cost and decrease sustainment cost
 - High modularity tends to lower overall acquisition cost and mitigates the overall cost associated with high production
- Sponsor – Navy/NPS

Defense Acquisition and Organizational Simulation

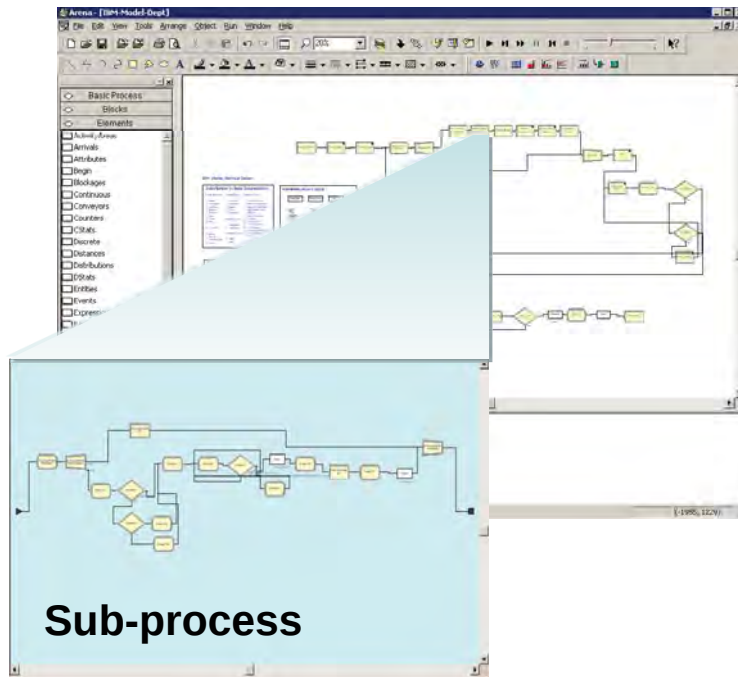


- Goal – represent organizational phenomena in simulation models (agent-based, discrete-event, system dynamics)
- Incorporate interactive computing concepts (character programming and drama management)
- Application to Predator acquisition:
 - Multi-actor decisions
 - Lead service selection
 - Military utility determination
- Sponsor – Air Force

Defense Acquisition and Systems Engineering (RT-16)



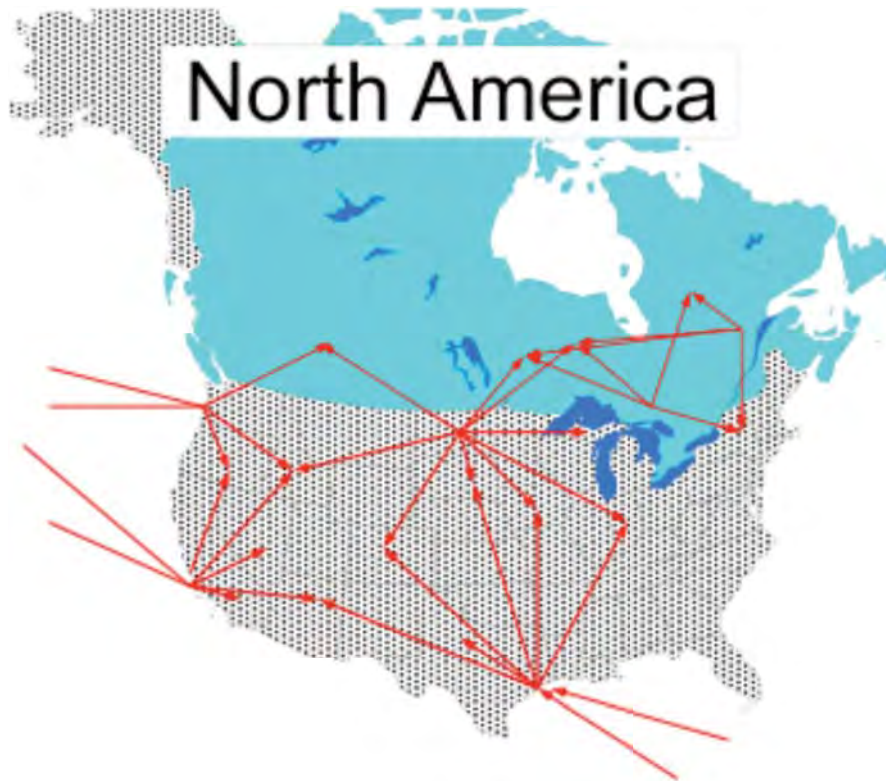
Services



Requirements and designs are represented as information artifacts that evolve and change as they traverse processes

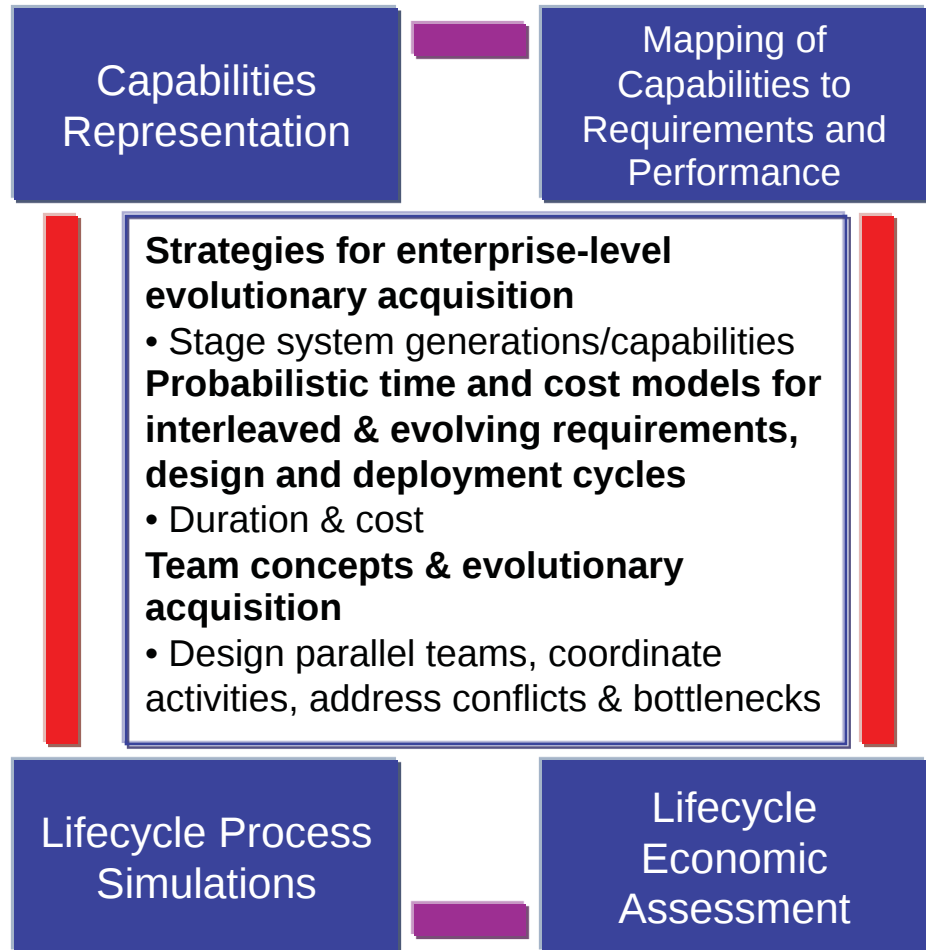
- Services constitute a majority of GDP
- Engineering design as a service – computer servers
- Time to market is key
- GT modeled and simulated computer server design processes
- Organizational designs and skill level mixes have a major impact on service effectiveness
- Sponsor – IBM

Energy



- Wind energy systems integrators face major cost issues in transport of components
- Multiples of \$100M annually
- GT developed an optimization tool for sourcing and transport of components
- Spreadsheet-based with trade-offs between usability and speed
- 10-15% cost reduction on sample runs vs. manual approach
- Sponsor – GE Energy

Enterprise IT Integration (RT-25)



- Enterprises face new challenges, requiring new capabilities
- This involves integration of new capabilities
- How are these translated in a disciplined manner to IT requirements
- This occurs in an evolutionary environment
- Need for tools
 - Represent capabilities and requirements
 - Facilitate experimentation and what-if analysis
- Sponsor – SERC
- Partners – GT and USC

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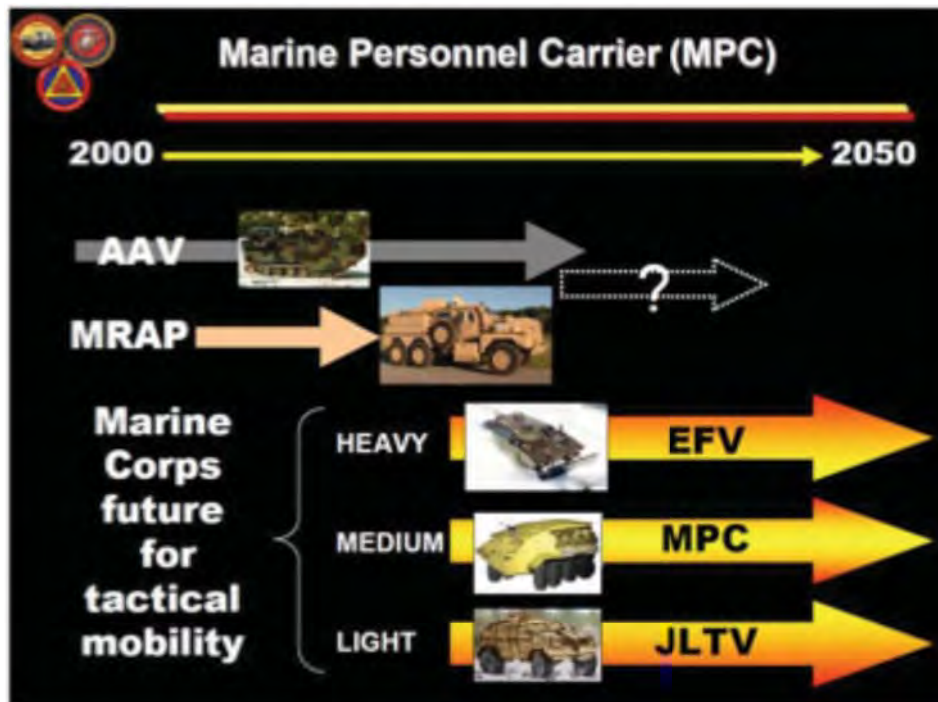
Collaborative D

Decision-makers afforded novel real-time, panoramic view of trade-offs and parametric sensitivities via advanced visualization features

Research conducted on capability-focused and inverse design to identify solutions that meet dynamic requirements



Real-time collaboration and decision making in a secure environment to solve real-world problems



Mobility
C-17 Transportable
Swim/Fording

IED Protection
Direct Fire Protection
Scalable Armor

Performance



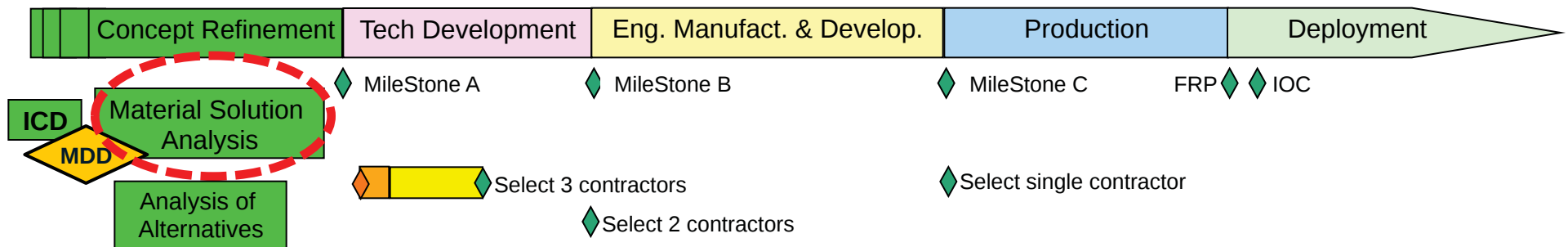
Protection

Payload

Combat Loaded Marines
Days of Supplies

performance payload

protection



Requirements Definition

Current toolset used to analyze selected mobility requirements and associated costs

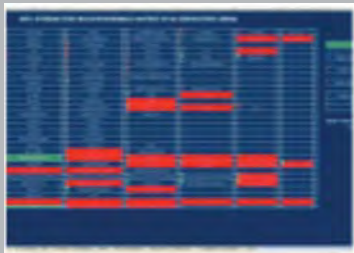
Source Selection

Current toolset may be used to assist source selection planning

Outcomes

- Better defined requirements with enabling performance
- Getting proposals that are closer to our goals, reducing risk to cost and schedule
- Guidance towards source selection

Sub-system Technology Selection Tool



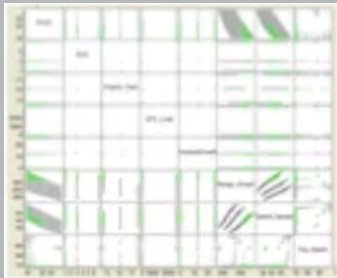
**Compare and prioritize
technology**

Vehicle Performance Generation Tool (VPGT)



**Generate valid
design solutions**

Statistical Data Analysis

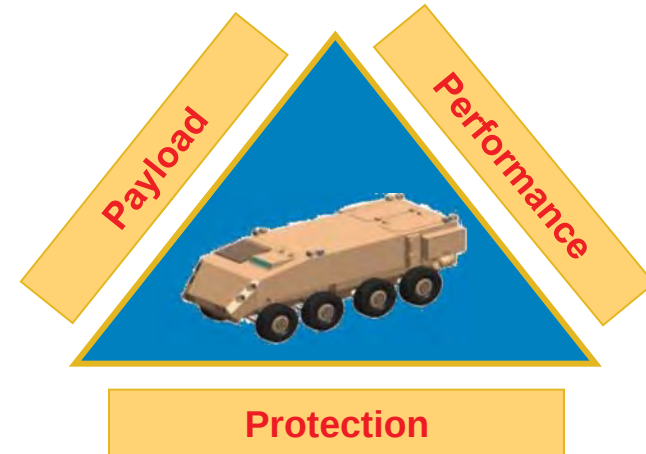


**Design space
exploration**

Vehicle Comparison Tool (VCT)



**Compare valid
design solutions**



Output : Recommendations for a
balanced, achievable
requirements document for MPC

Navigate through the possible combinations through:

- A series of technology compatibilities (i.e. some technologies options for one subsystem may not be compatible with technologies in another subsystem)
- Technology filters (i.e. all must be at least a TRL = 8)
- Technologies that will benefit important requirements

MPC INTERACTIVE RECONFIGURABLE MATRIX OF ALTERNATIVES (IRMA)

Swim Capability	Integral Stern	No Swim	Payload/Aircrew Removal	Deal Cooling	Air Bladder
Swim - Propulsion	Propeller	Jet Pod - Shaft Driven	High Thrust Pod - Shaft Driven	Jet - Hydraulic Driven	Jet - Electric Motor Driven
Front Suspension Architecture	SLA (Front)	Live Axle (Front)	Strut (Front)		
Rear Suspension Architecture	SLA	Live Axle	Trailing Arm	Strut	Multi-link
Suspension Actuation - Spring	Coil Springs	Leaf	Torsion Bar	Air Bag	Hydropneumatic
Suspension Actuation - Damper	Passive	2-stage switchable	Continuously Adjustable SV	Continuously Adjustable MR	
Steering	1 & 2	1, 2, & 4	1, 2, 3, 4		
Chassis Systems - Brakes	Hydraulic Brakes	Pneumatic Brakes	Pneumatic over Hydraulic Brakes		
Chassis - Run Flat	Hutchinson	Drive Dynamics			
Chassis - Tires	Michelin XM1	Michelin XZ1	Ground-Medium Tactical		
Powertrain - Main Powerplant	CI - Inline	CI - Vee	Turbine		
Electrical Power Generation	Alternative	Deal Alternator	ISG/ISA		
Electrical Storage Architecture	Lead Acid	Carbon Foam Lead Acid	Ultra Cap		
Powertrain cooling - Radiator	Brazed Aluminum Tube	Aluminum Bar & Plate	Copper Bracs		
Powertrain Cooling - Charged Air Cooler	Air to Air	Air to Water			
Powertrain Cooling - Oil Cooler	Oil to Air	Oil to Water			
Powertrain Cooling - Fuel Cooler	Fuel to Air	Fuel to Water			
Powertrain Cooling - Condenser	Mechanically Assembled	Brazed Tube & Fin			
Powertrain Cooling - Engine Cooling Fan	Hydraulic	Mechanical	Electric		
Thermal Systems - Climate Control	Enhanced R134a	CO2	Alternative Non CO2		
Thermal Systems - Waste Heat Recovery	No Waste Heat Recovery	Thermal Acoustics	Metal Hydrides		
Driveline - Transmission	5 Speed A/T	6 Speed Wide Ratio A/T	7 Speed A/T		
Driveline - Transfer Case	Electric Hybrid Trans	Continuously Variable Trans (CVT)	Integrated Trans/Transfer Case		
Driveline - Differentials	Passive Locking Single Speed Transfer Case	7 Speed Transfer Case: Mechanical Locking	7 Speed Transfer Case: Torque Vectoring		
Driveline - Hubs	Differential - Open	Small Size Limited Slip (LSI)	Electric Lock	Differential - Torque Vectoring	Torque Vectoring Axle
Driveline - Shafts	Bevel Gear	Bevel Gear Next Generation	Planetary Gears		
TRL	1	2	3	4	5
TRL	7	8	9		

Darker circle indicate technologies within a subsystem group that has the greatest impact on the variability of the highest ranked requirements

Subsystem attributes may have little impact on requirements attributes

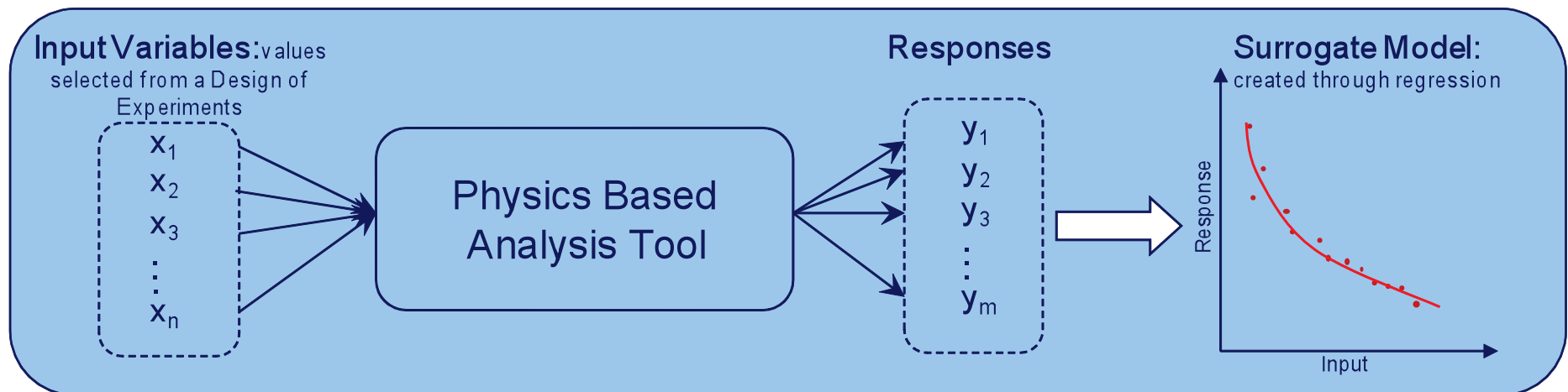
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Rear Suspension Architecture	SLA	Live Axle	Trailing Arm	Steer	Multi-Axle
Suspension Actuation - Spring	Coil Springs	Leaf	Torsion Bar	Air Bag	Hydro-pneumatic
Suspension Actuation - Damper	Pneumatic	2-Stage Adjustable	Continuously Adjustable SR	Continuously Adjustable MR	
Steering	1 & 2	1, 2, & 4	1, 2, 3, 4		
Chassis Systems - Brakes	Hydraulic Brakes	Pneumatic Brakes	Pneumatic over Hydraulic Brakes		
Chassis - Run Flat	Run-flat tires	Drive Equipped			
Chassis - Tires	Michelin RMB	Michelin XZL	Scallop or Medium Tactical	Scallop or Heavy Tactical	
Powertrain - Main Powerplant	CI - In-line	CI - Vee	Turbine	DBTC	
Electrical Power Generation	Alternator	Dual Alternator	WGSMA		
Electrical Storage Architecture	Lead Acid	Carbon Fiber Lead Acid	Ultra Cap	SMES	Lithium
Powertrain cooling - Radiator	Brazed Aluminum Tube	Aluminum Bar & Plate	Copper Brackets		
Powertrain Cooling - Charged Air Cooler	Air to Air	Air to Water			
Powertrain Cooling - Oil Cooler	Oil to Air	Oil to Water			
Powertrain Cooling - Fuel Cooler	Fuel to Air	Fuel to Water			
Powertrain Cooling - Condenser	Mechanically Assembled	Brazed Tube & Fin			
Powertrain Cooling - Engine Cooling Fan	Hydraulic	Mechanical	Electric		
Thermal Systems - Climate Control	Enhanced FIDRs	CO2	Alternative Non-CO2		
Thermal Systems - Waste Heat Recovery	No Waste Heat Recovery	Thermal Assemblies	Metal Hydrides	Thermal electric	
Driveline - Transmission	5 Speed A/T	8 Speed Wide Ratio A/T	7 Speed A/T	12 Speed A/T	Automated Manual Trans (AMT)
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Driveline - Hubs	Differential - Open	Small Size Limited Slip (LSO)	Electric Lock	Differential - Torque Vectoring	Torque Vectoring Axle
Driveline - Shafts	Bevel Gear	Bevel Gear Next Generation	Planetary Gears		
TRL	1	2	3	4	5
TRL	7	8	9		

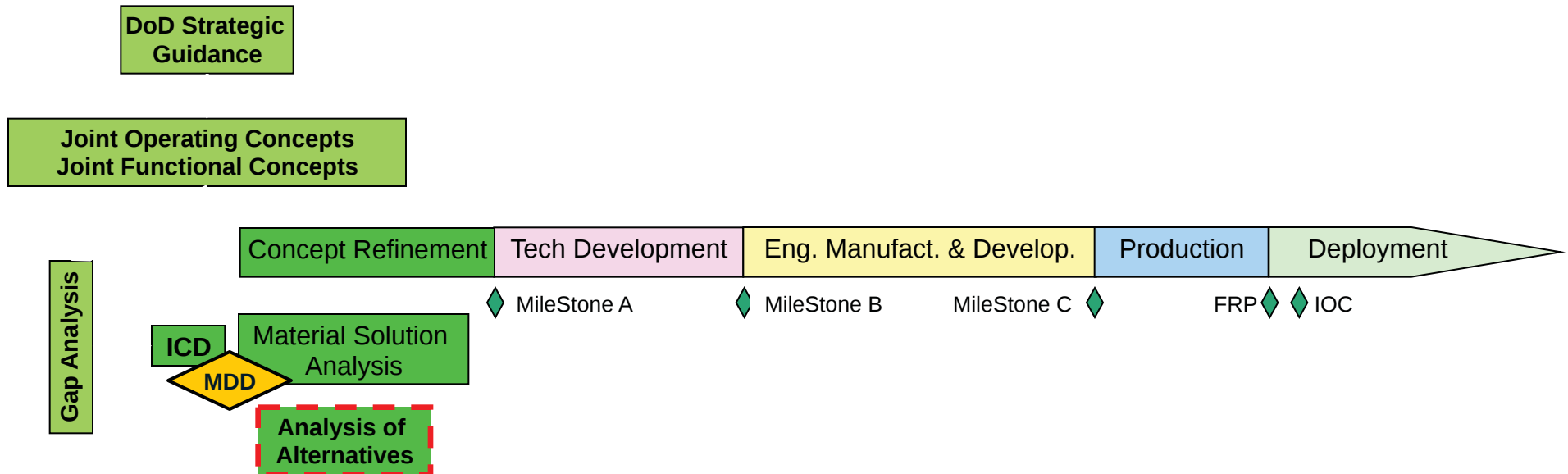
Vehicle architectures may be selected

Surrogate models



Bringing Modeling & Simulation Forward in the Decision Making Process

24



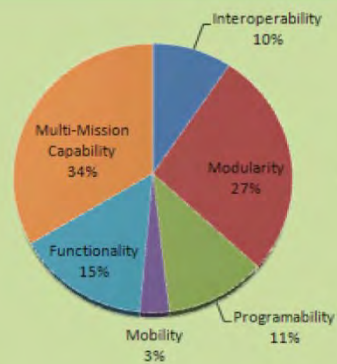
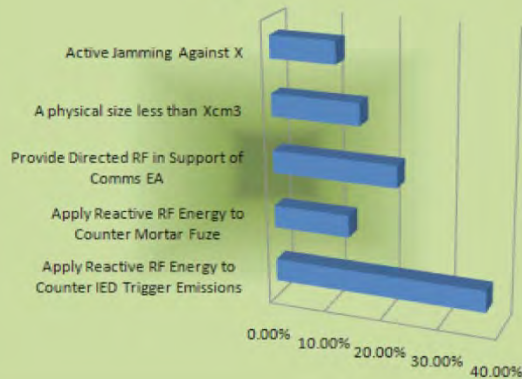
- **GTRI IEWS Program Support**
 - ✓ IEWS Counter RC-IED Technology Discovery
 - Pre-AoA planning
 - Provide Subject Matter Expertise as necessary

Capabilities

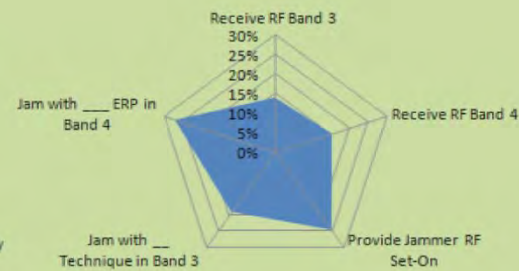


Georgia Tech Research Institute

Requirements



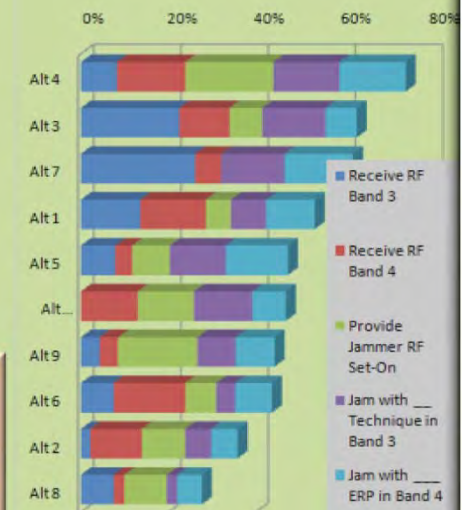
Functions



Architecture

Antenna Type	Conformal	Directional	Omni-Directional		
# Receive Channels	1	2	3	4	5
# Transmit Channels	1	2	3	4	5
Transmitter	Solid State	Tube			
Transmit Power /	a	b	c	d	e
Technique	ERP	Software Defined Radio			

Alternative Scores



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Mavris, et al. [see related topics in Ender et al.]
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See also our work
in RT21 and RT24 →

Model-Based Systems Engineering Using SysML

Excavator Testbed (2007-2009)

Abstract

This presentation highlights Phase 1 results from a modeling & simulation effort that integrates design and assessment using SysML. An excavator testbed illustrates interconnecting simulation models with associated diverse system models, design models, and manufacturing models. We then overview Phase 2 work-in-process including a mobile robotics testbed and associated SysML-driven operations demonstration.

The overall goal is to enable advanced model-based systems engineering (MBSE) in particular and model-based X (MBX) [1] in general. Our method employs SysML as the primary technology to achieve multi-level multi-fidelity interoperability, while at the same time leveraging conventional modeling & simulation tools including mechanical CAD, factory CAD, spreadsheets, math solvers, finite element analysis (FEA), discrete event solvers, and optimization tools.

This Part 1 presentation overviews the project context and several specific components. Part 2 focuses on manufacturing aspects including factory design, process planning, and throughput simulation.

This work is sponsored by several organizations including Lockheed and Deere and is part of the Modeling & Simulation Interoperability Team [2] in the INCOSE MBSE Challenge (with applications to mechatronics as an example domain).

[1] The X in MBX includes engineering (MBE), manufacturing (MBM), and potentially other scopes and contexts such as model-based enterprises (MBE).

[2] <http://www.pslm.gatech.edu/projects/incose-mbse-msi/>

Citations

- RS Peak, CJJ Paredis, LF McGinnis (2009-04) Model-Based SE Using SysML—Part 1: Integrating Design and Assessment M&S. NDIA M&S Committee Meeting, Arlington, Virginia.

- LF McGinnis (2009-04) Model-Based SE Using SysML—Part 2: Integrating Manufacturing Design and Simulation. NDIA M&S Committee Meeting, Arlington, Virginia.

- Main team web page: - These publications:

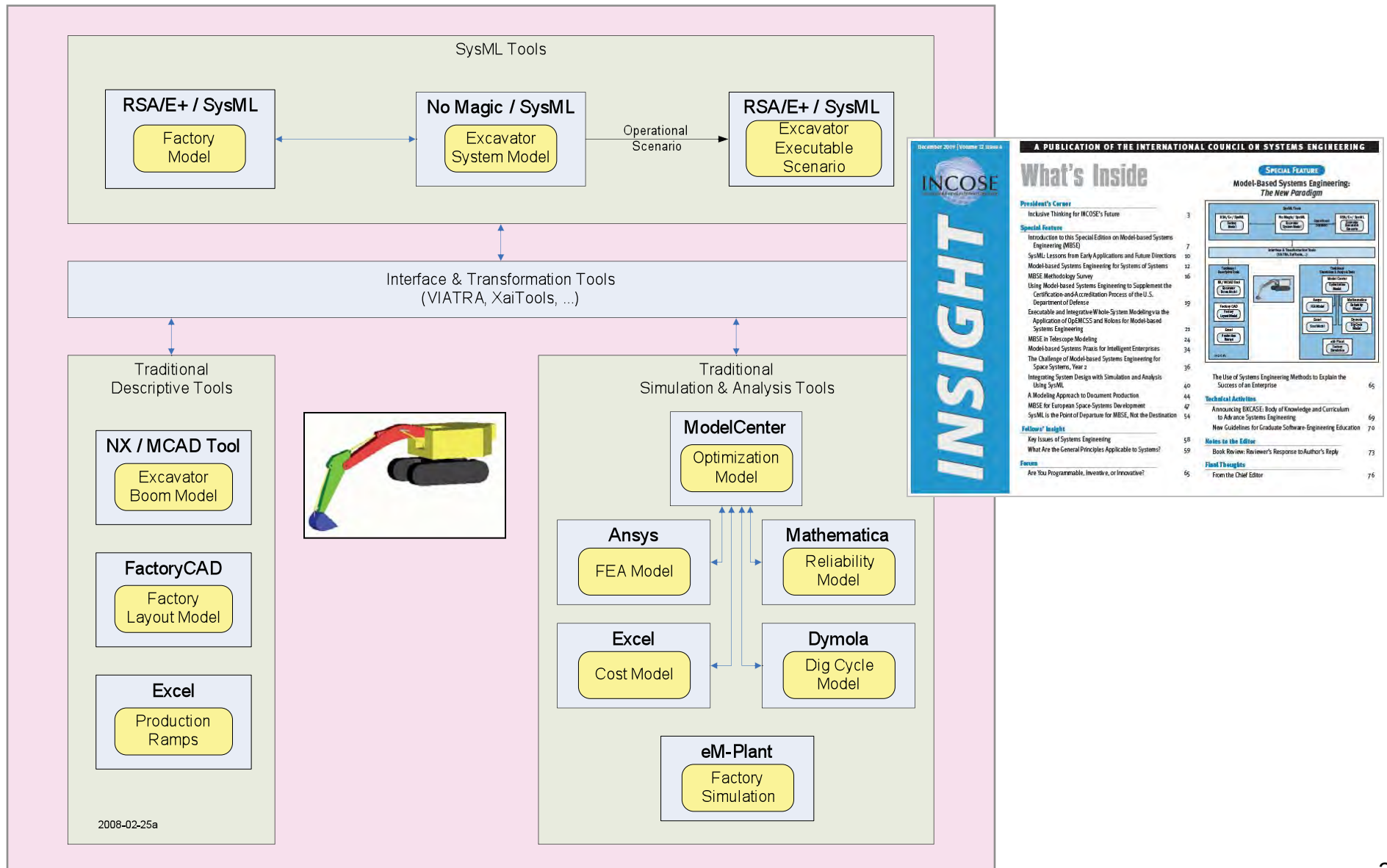
<http://www.pslm.gatech.edu/projects/incose-mbse-msi/> <http://eislabs.gatech.edu/pubs/seminars-etc/2009-04-ndia-ms/>

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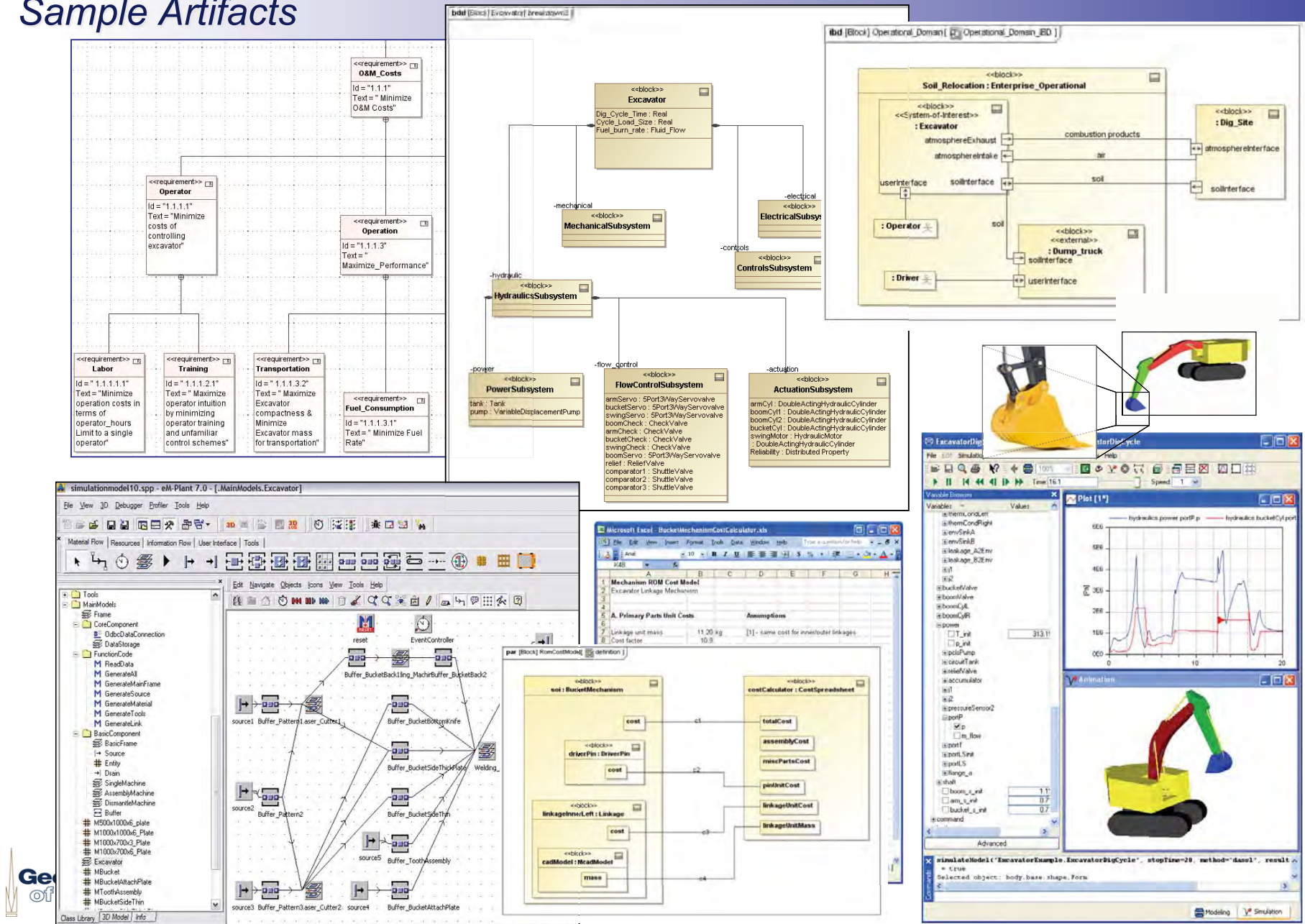
Excavator Modeling & Simulation Testbed

Tool Categories View



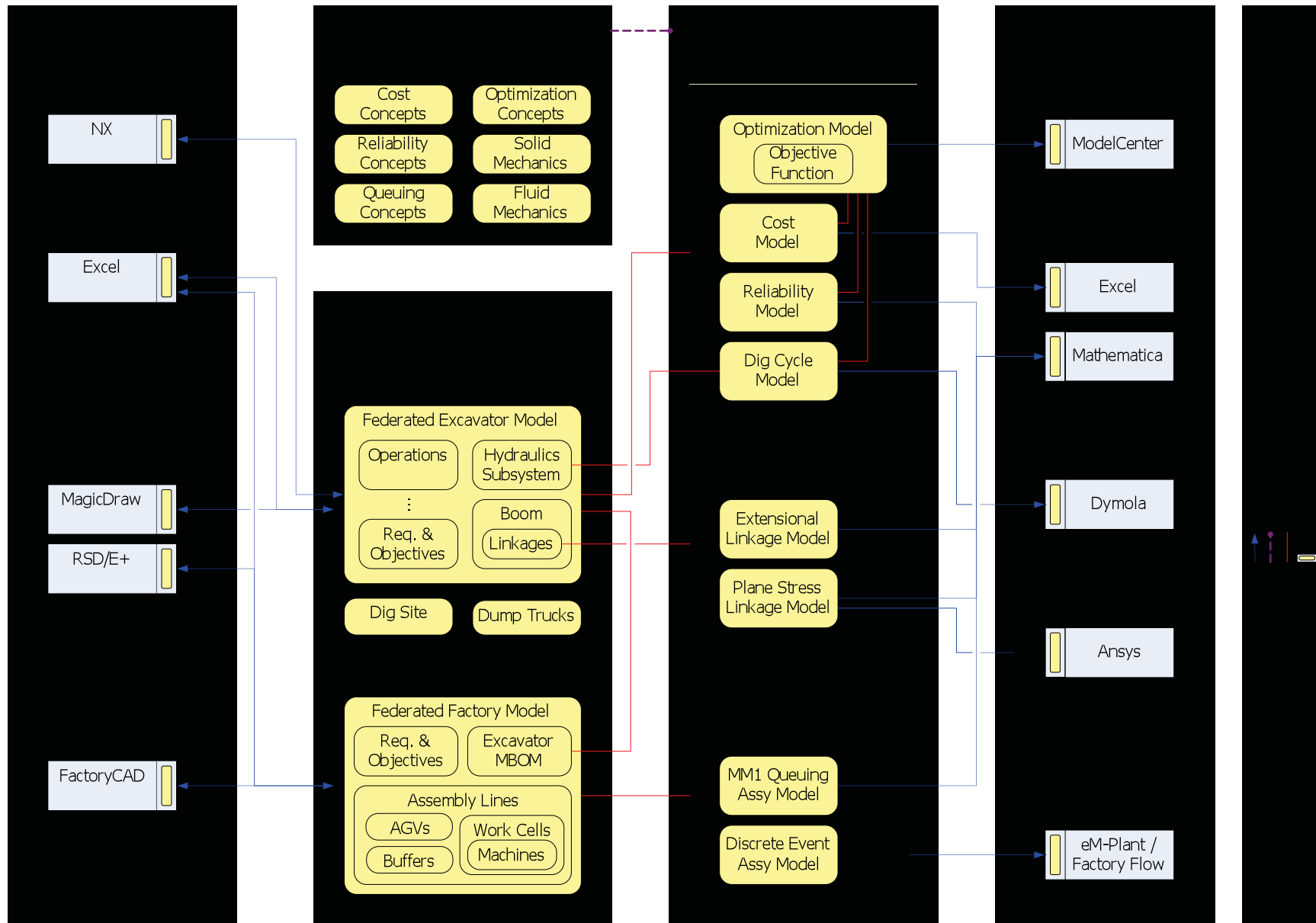
Excavator Modeling & Simulation Testbed

Sample Artifacts



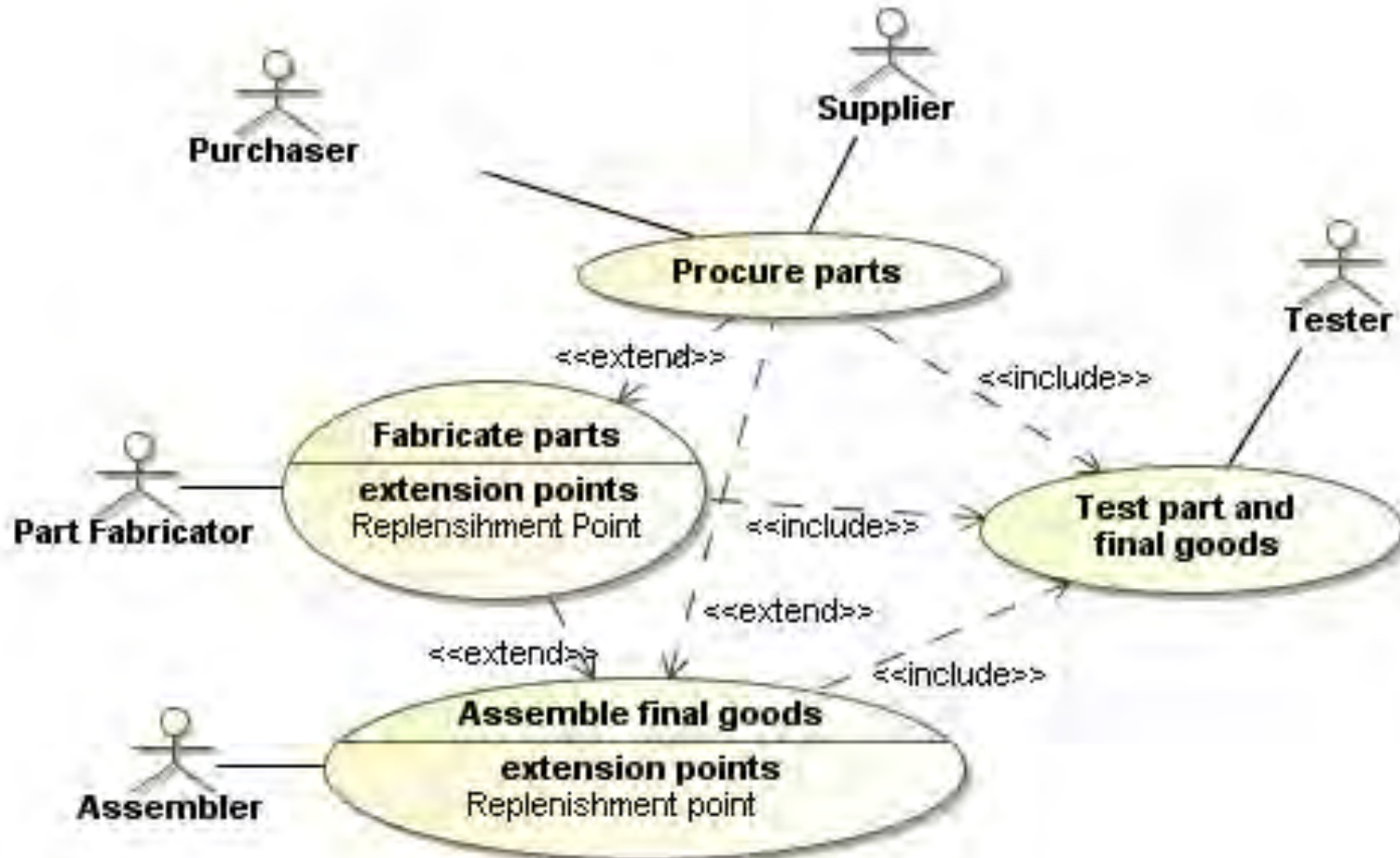
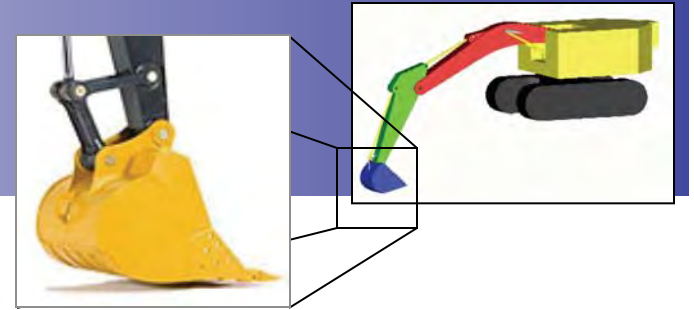
Excavator Modeling & Simulation Testbed

Interoperability Patterns View (MSI Panorama per MIM patterns)



Manufacturing Use Cases

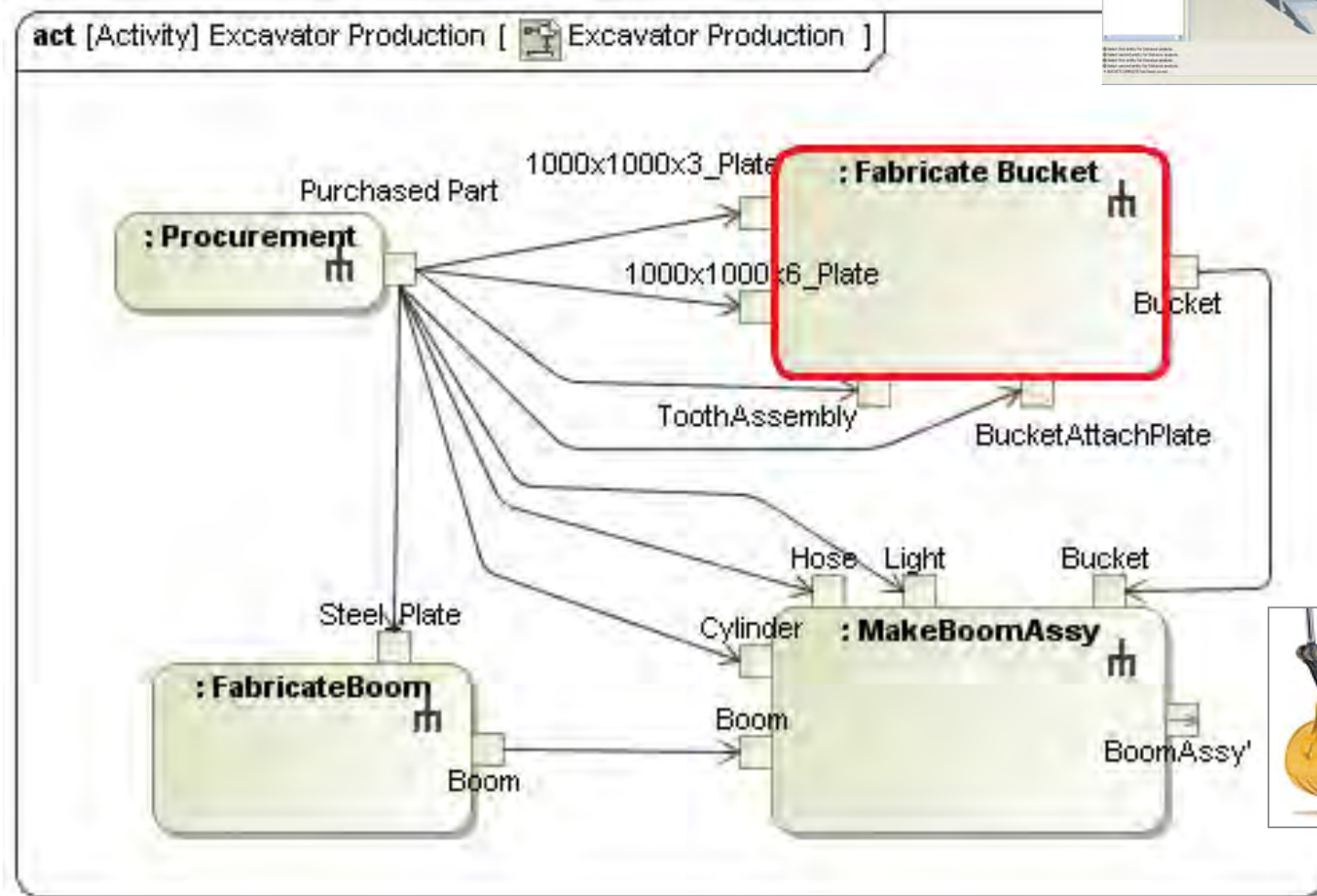
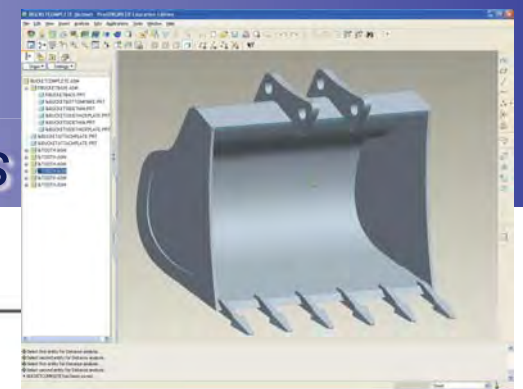
[McGinnis et al.]



Process Planning Model

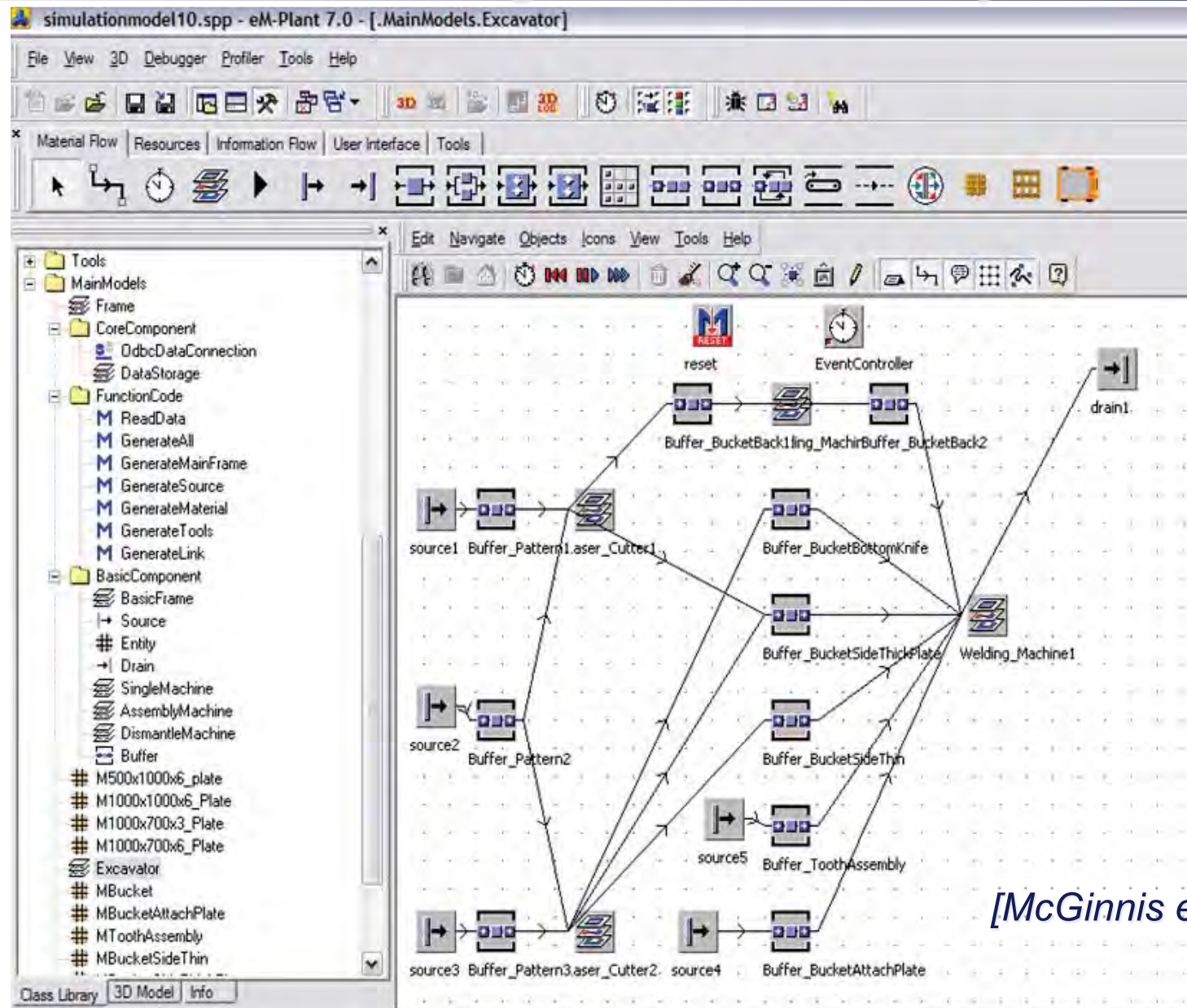
Functional modeling style using SysML activities

[McGinnis et al.]



eM-Plant Simulation

Discrete event model auto-generated from SysML



[McGinnis et al.]

Exploration of System Architectures

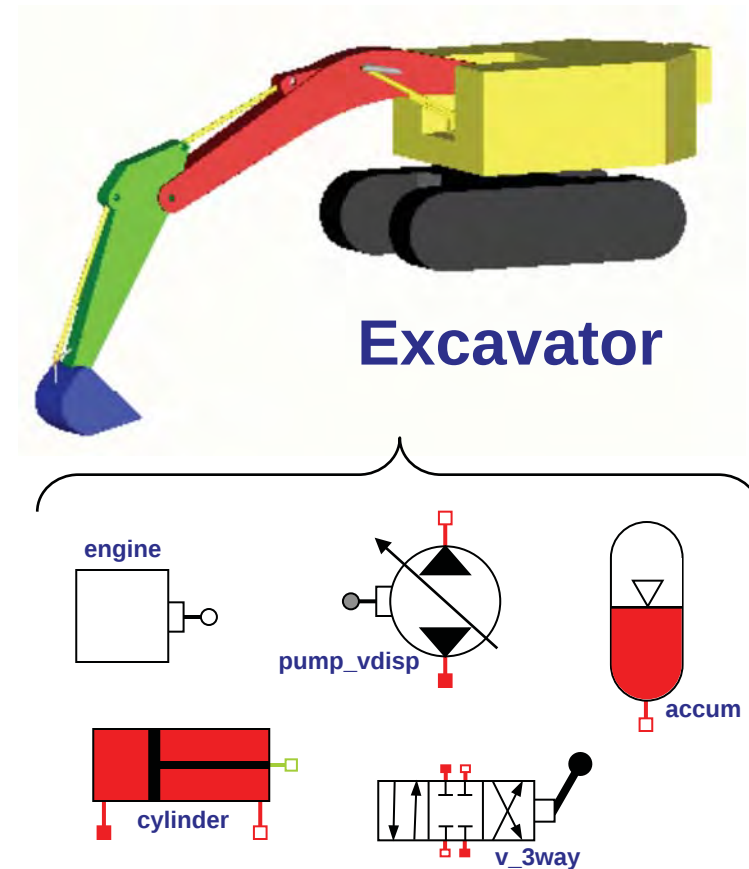
Problem Statement

Given:

- Component models
- Objectives / preferences

Find:

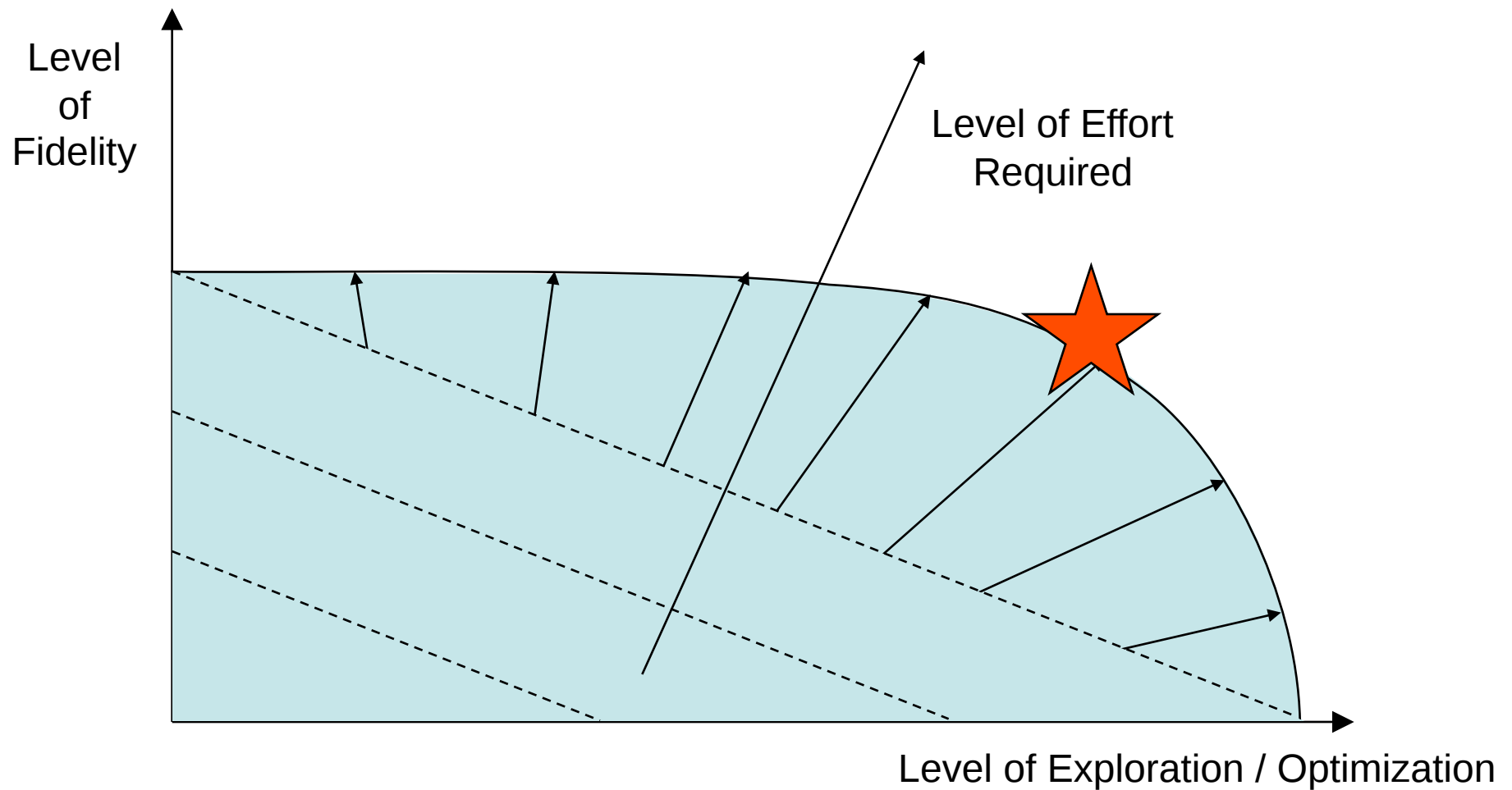
- Best system architecture
- Best component parameters
- Best controller



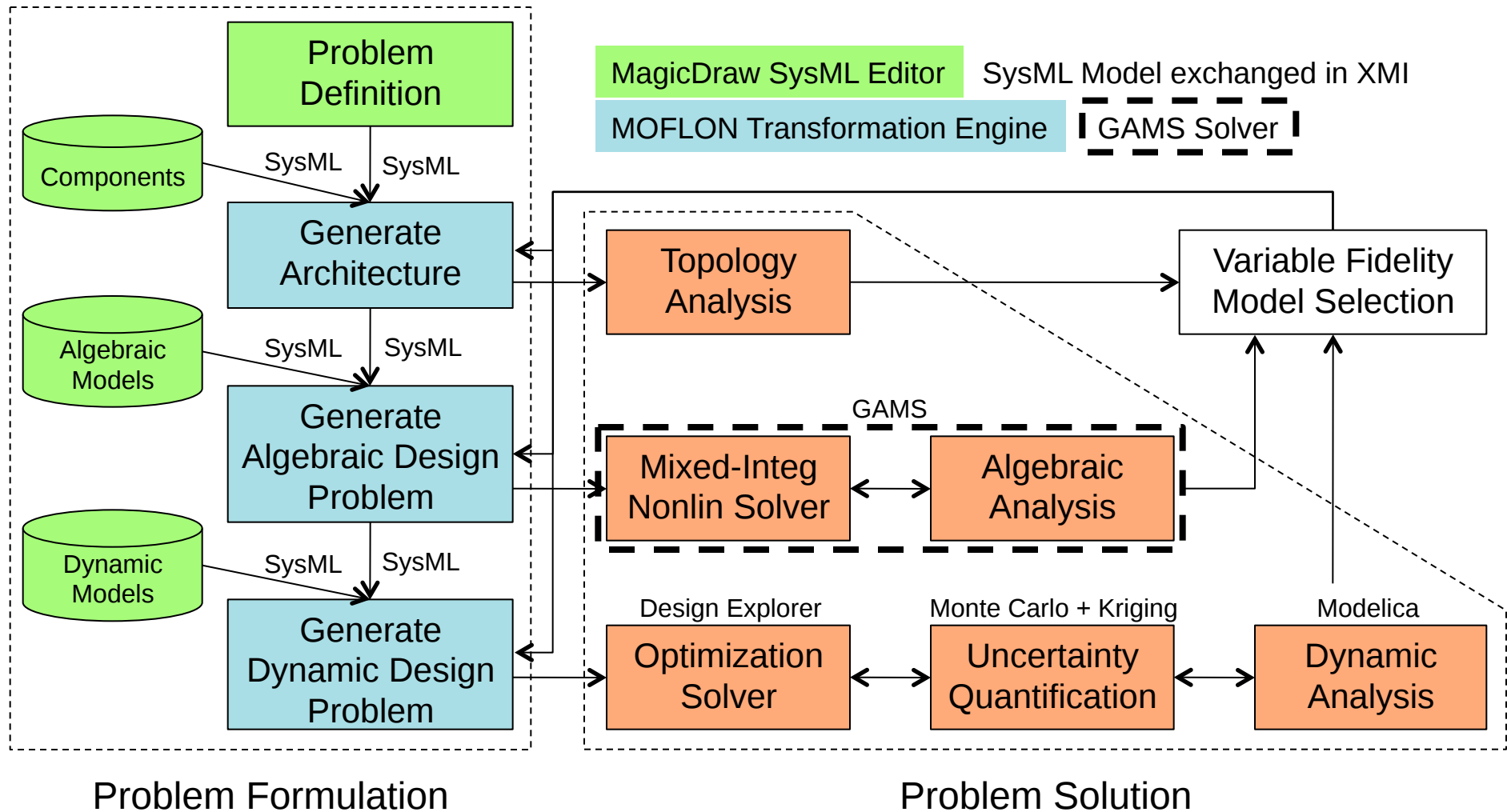
How to connect and size these?

Designer's Dilemma

M&S Risk/Benefit vs. Cost



Architecture Exploration Framework



Problem Formulation

Problem Solution

Both Problem Formulation and Problem Solution phases are implemented in ModelCenter

SysML Parametrics

Peak et al.

- ◆ Road scanning system using unmanned aerial vehicle (UAVs)
- ◆ UAV-based missile interceptor system trade study
- ◆ Space systems (tutorials): orbit planning; mass/cost roll-ups
- ◆ Space systems (studies/pilots): FireSat (INCOSE SSWG), ...
- ◆ Space systems (actuals): science merit function, ...
- ◆ Environmentally-conscious energy systems / smart grid
- ◆ Manufacturing “green-ness” / sustainability assessments
- ◆ Regional water management systems (e.g. South Florida)

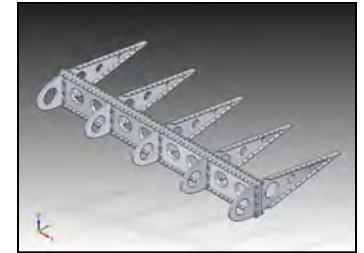
...

- ◆ Mechanical part design and analysis (FEA)

...

- ➔ ◆ Wind turbine supply chain management
- ◆ Insurance claims processing and website capacity model
- ◆ Financial model for small businesses
- ◆ Banking service levels model

...

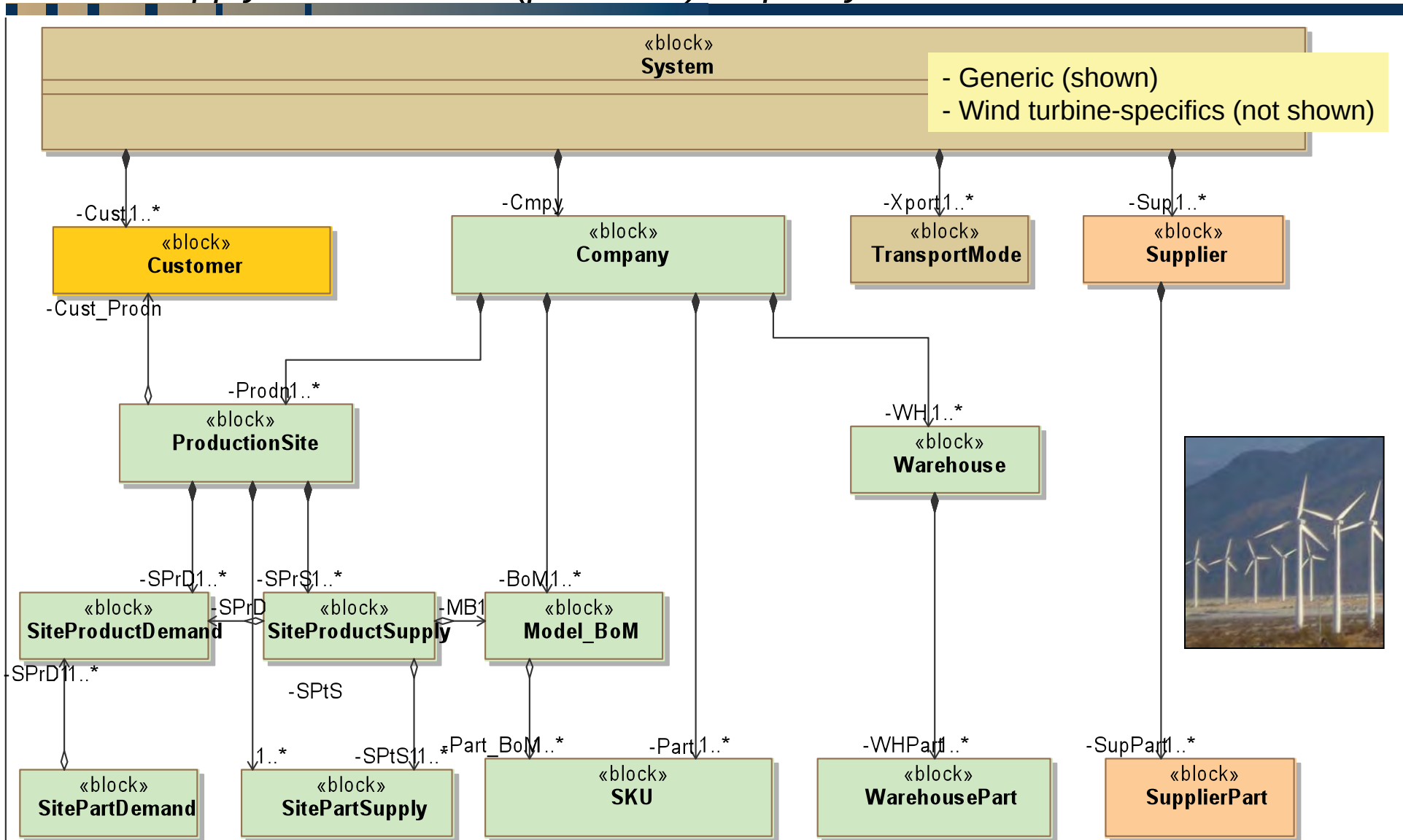


*Next-Generation
Spreadsheet Technology++
(object-oriented, multi-dimensional, ...)*



SysML Model: Global Supply Chain Mgt. & Optimization

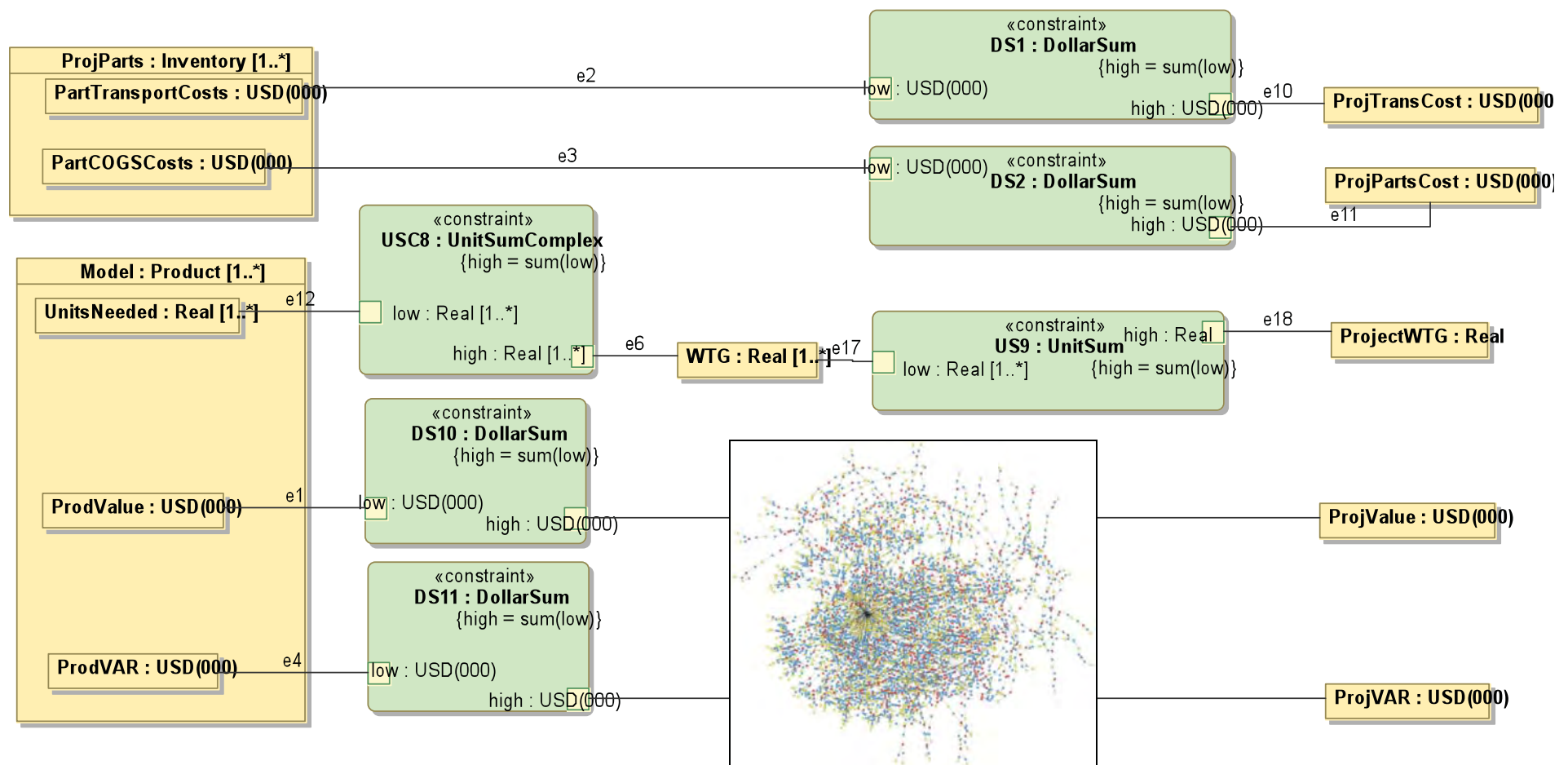
supply chain metrics (per-week): capacity, cost, lateness, risk, ...



Supply Chain Model – SysML Parametrics

Connect to Optimization Models, Compute Value-at-Risk

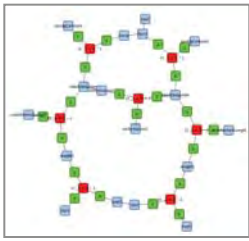
Ex. Given 100's of product orders and sourcing plans for the next 12 months, what percent of my business is at-risk if Supplier X does not deliver, or if Part Y becomes obsolete?



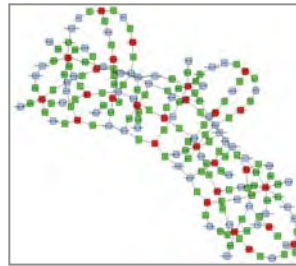
Model “DNA Signatures” Using SysML Parametrics

Panorama Tool by Andy Scott (Undergrad Research Asst.) and Russell Peak (Director, Modeling & Simulation Lab)
Examples as of ~9/2009 — Low/Medium Complexity

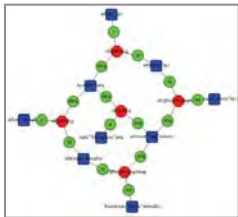
a. Snowman



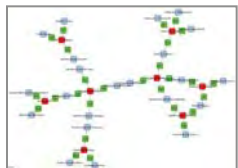
e. Cactus



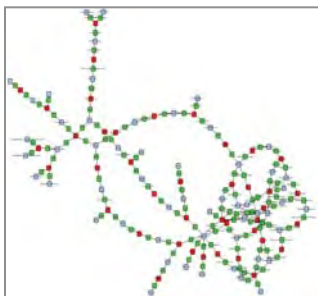
b. Mini Snowman



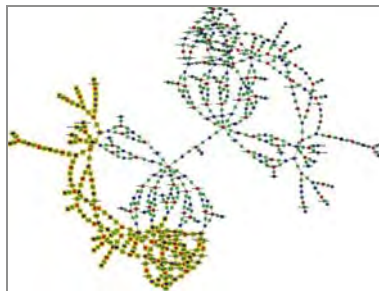
c. Snowflake



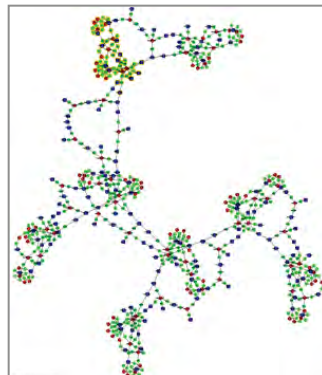
d. Mouse



f. ?



g. Robot



Test: Match the actual model titles (below) to their “DNA signatures” with imagined titles (left).

___ **g** ___ 1. South Florida water mgt. (hydrology) model

___ **a** ___ 2. 2-spring physics model

___ **e** ___ 3. 3-year company financial model

___ **c** ___ 4. UAV road scanning system model

___ **b** ___ 5. Car gas mileage model

___ **d** ___ 6. Airframe mechanical part model

___ **f** ___ 7. Design verification model
(automated test for two Item 6. designs)

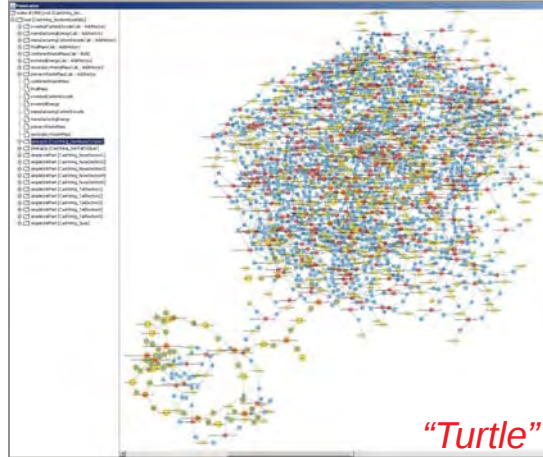
Recent Models: ~Medium Complexity

supply chain metrics



"Galaxy with Black Hole"

mfg. sustainability: airframe wing



"Turtle"

electronics recycling network



"Tumbleweed"

mfg. sustainability: automotive transmissions



"Turtle Bird"



"Angler Fish"

SysML/MBSE Curriculum & Formats

Statistics as of Sept 2010 — www.pslm.gatech.edu/courses

- ◆ Full-semester Georgia Tech academic courses
 - ISYE / ME 8813 & 4803: Since Fall 2007 (~95 students total)
- ◆ Industry short courses
 - Collaborative development & delivery with InterCAX LLC
 - Multiple [offerings,~students] and formats since Aug 2008
 - » SysML 101 [14,~260]; SysML 102 (hands-on) [12,~205]
 - Modes:
 - » Onsite at industry/government locations
 - » Open enrollment via Georgia Tech (Atlanta, DC, Orlando, Vegas, ...)
 - » Web-based “live” since Apr 2010
 - Coming soon: 201/202, 301/302 (int/adv concepts, OCSMP prep, ...)
- ◆ Georgia Tech Professional Masters academic courses
 - Professional Masters in Applied Systems Engineering
www.pmase.gatech.edu
 - ASE 6005 SysML-based MBSE course - Summer 2010
 - ASE 6006 SE Lab (SysML-based system design project) - Fall 2010

Contents

- Introduction
- Selected SE-related efforts
 - Professional Masters in SE (PMASE)
Bishop, et al.
 - Tennenbaum Institute (TI)
Bodner, Rouse, et al.
 - GTRI SE Initiative
Ender, et al.
 - Aerospace Systems Design Lab (ASDL)
Mavris, et al.
 - Model-Based SE Center (MBSEC)
McGinnis, Paredis, Peak, et al.

*See also our work
in RT16 and RT25*

*See also our work
in RT21 and RT24*

- ➡ • Summary

Georgia Tech as part of SERC



- Pleased with collaboration in SERC to date
- Looking forward to new opportunities in SERC together

