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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(other main contributors)

Georgia Institute of Technology

SYSTEMS ENGINEERING Research Center

Report Documentation Page

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  - GTRI SE Initiative
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  - Aerospace Systems Design Lab (ASDL)
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    McGinnis, Paredis, Peak, et al.
- Summary

Georgia Tech Fun Facts

Georgia Institute of Technology

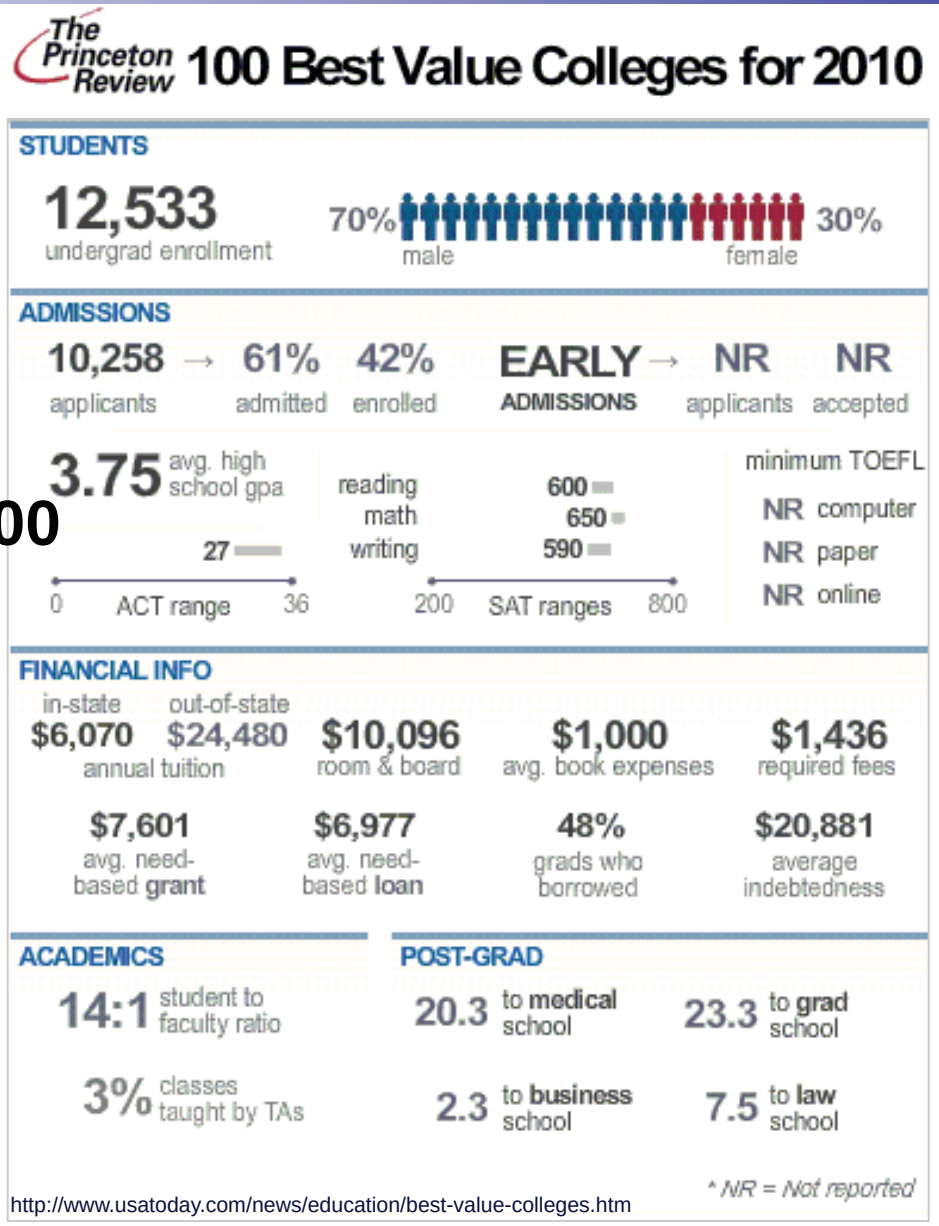
1885	1903	1948	1996	Mascots
Founded in Atlanta *Faculty* 5 Professors 5 Shop Supervisors *Students* 129 undergrads in Mechanical Engineering	First full-time football coach *John Heisman*	Renamed *Georgia Institute of Technology*	Served as Olympic Village for 10,000+ athletes/staff	

Georgia Institute of Technology

Georgia Tech Statistics

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

engineering: ~11,000



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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**

Most material is also available in short course fo in SE certificate program (www.pe.gatech.edu)

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The PMASE Curriculum

Core Curriculum

ASE 6001: Fund in Modern SE

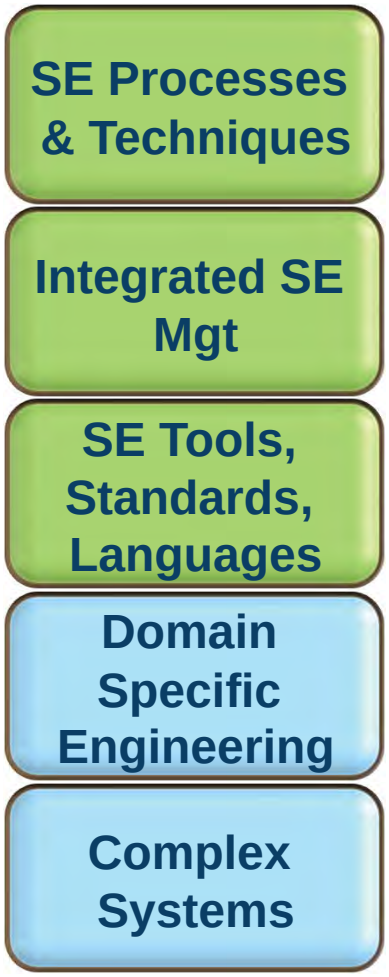
ASE 6002: Sys Design & Analysis

ASE 6003: M&S for SE

ASE 6004: Leading SE Teams

ASE 60X5: Advanced Topics in SE
- SysML
- HSI

ASE 6006: SE Lab



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

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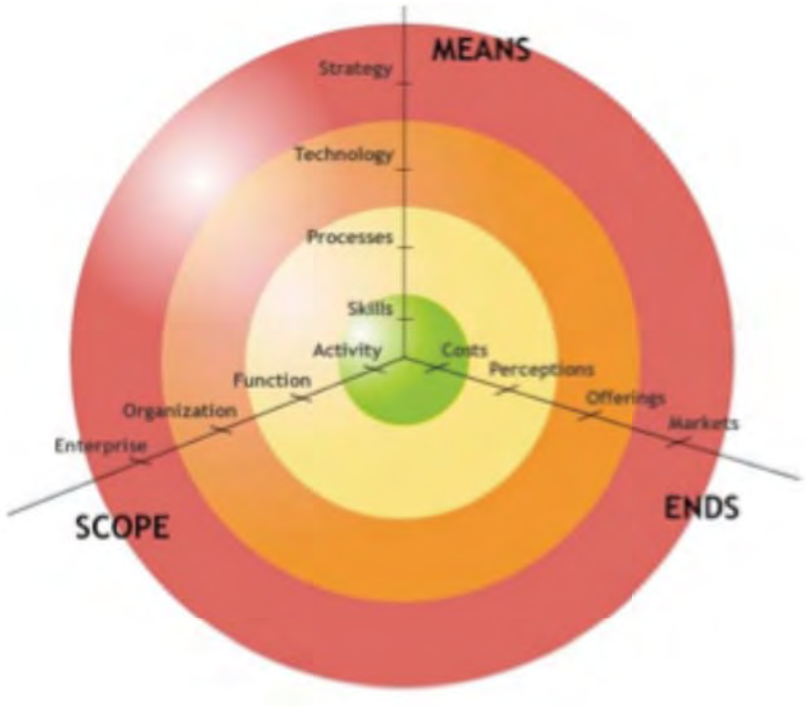
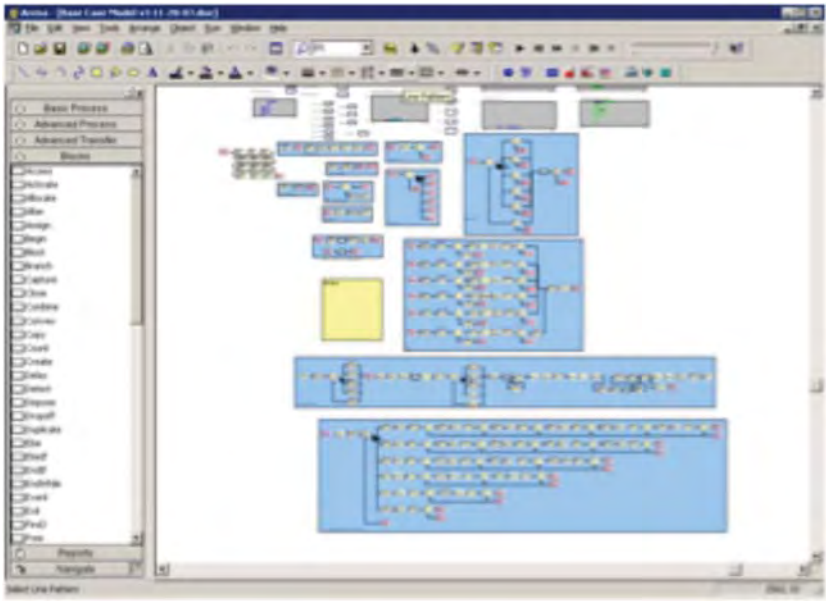
Tennenbaum Institute



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

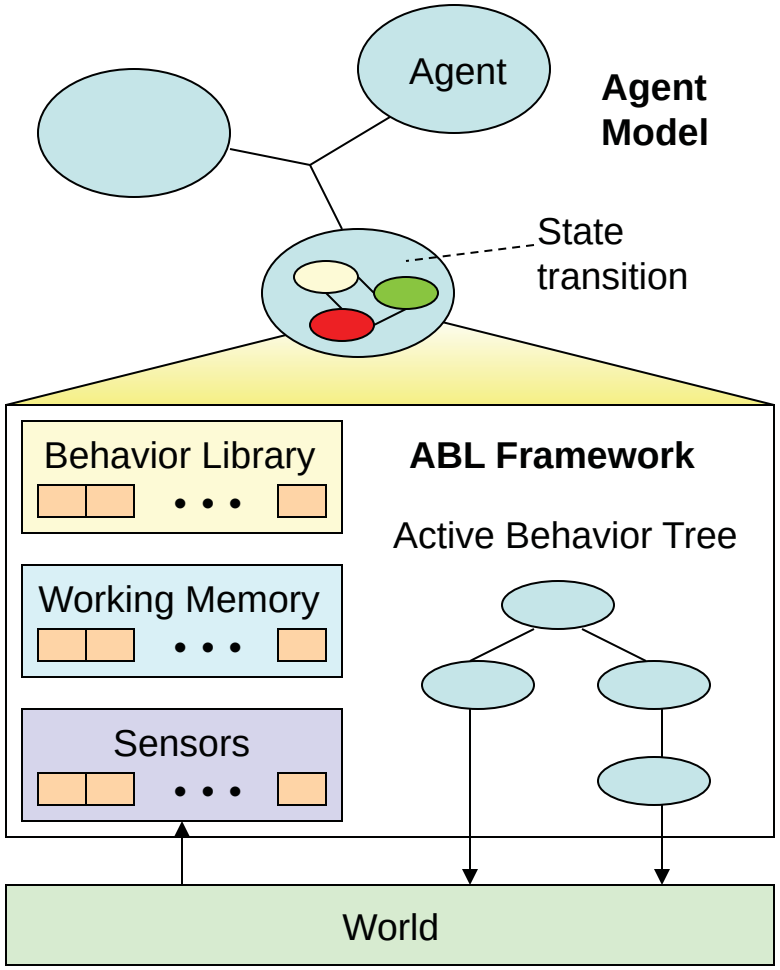
Defense Acquisition



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)

Georgia Tech Tennenbaum Institute

Sponsor – SERC/ DAU
Partners – GT, Purdue, Stevens, USC

Personality Background Characteristics Model

SE Competency Taxonomy

Learning Moments

User Profile

Customization

Presentation Engine
- User decisions
- Results (schedule/budget)

Simulation Engine
- Program results (user decisions & randomness)

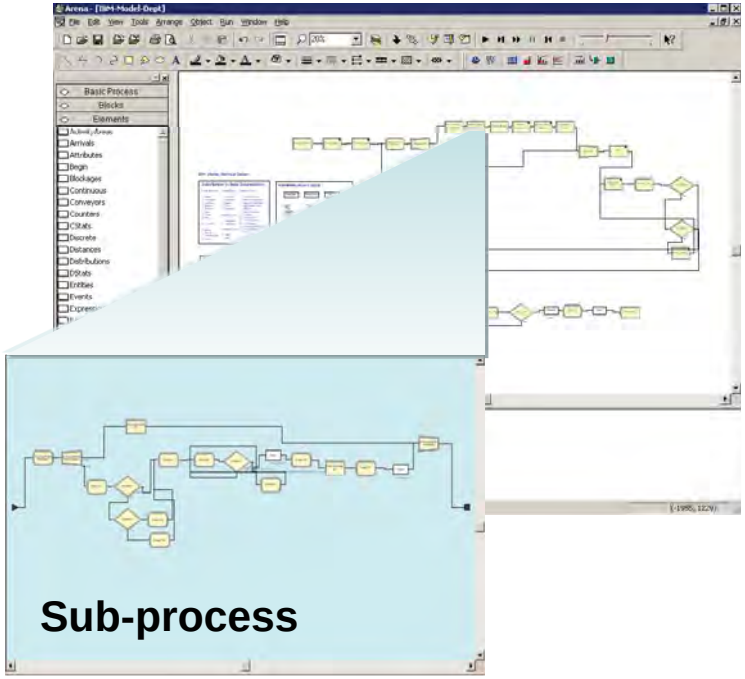
NPC Engine
- Colleague interactions

Learning/Reflection

Framework exercise

Experience Database

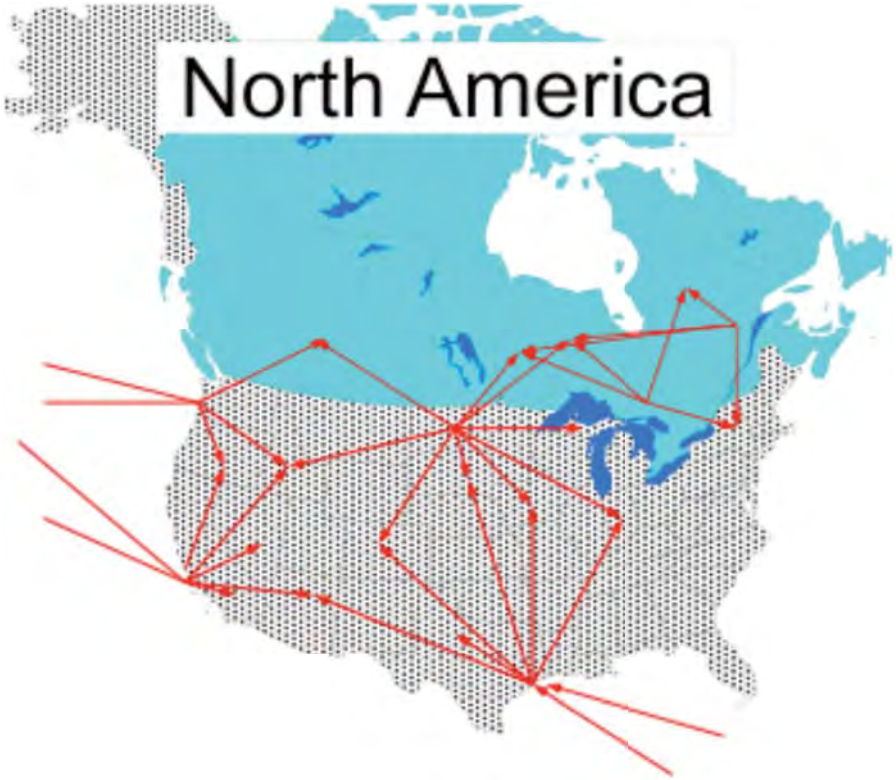
Services



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

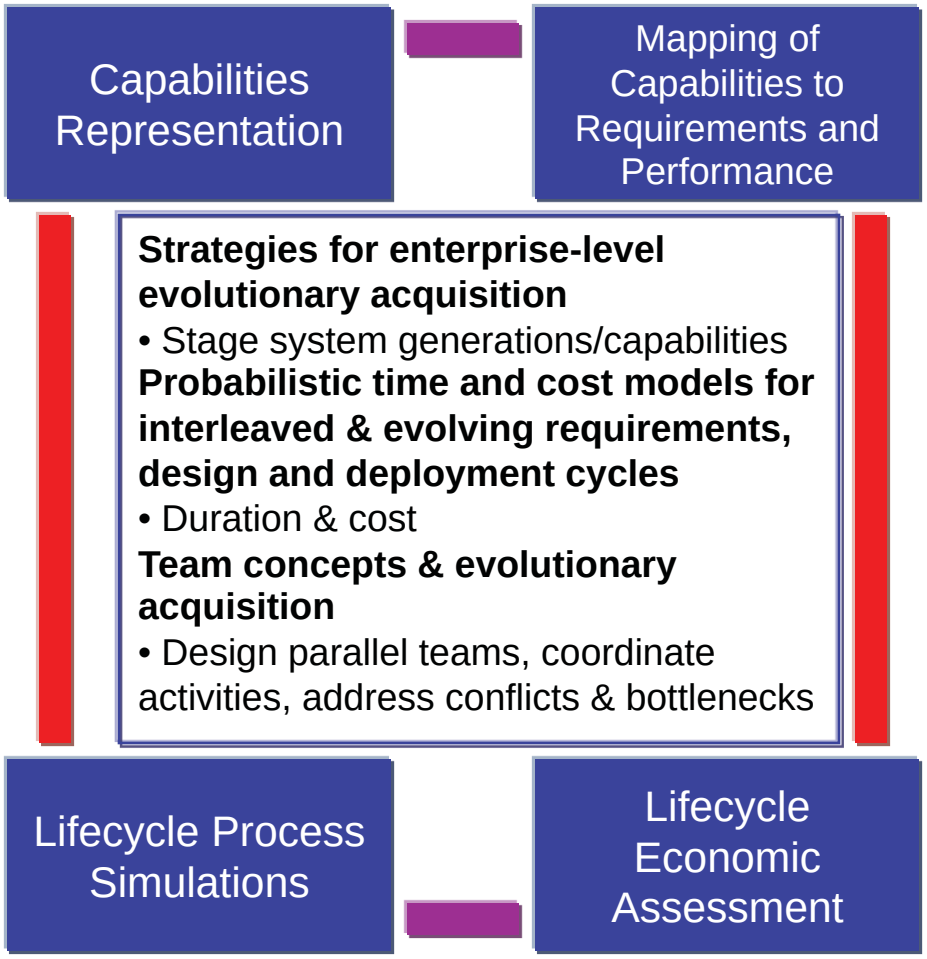
- Services constitute a majority of GDP
- Engineering design as a service – computer servers
- Time to market is key
- GT modeled and simulated computer server design processes
- Organizational designs and skill level mixes have a major impact on service effectiveness
- Sponsor – IBM

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[illegible]kind

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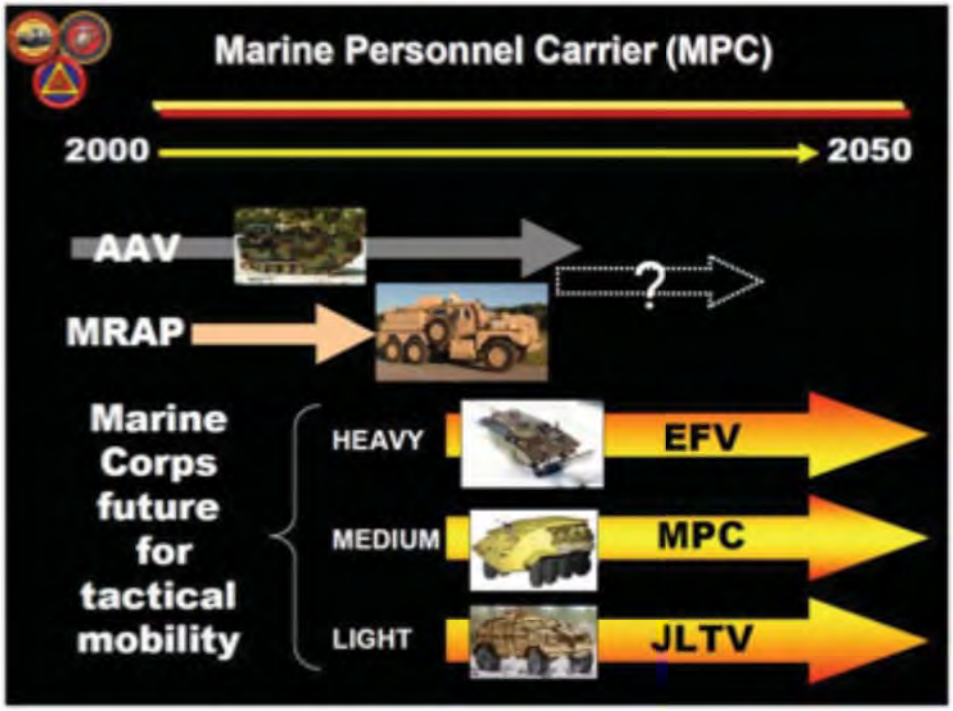
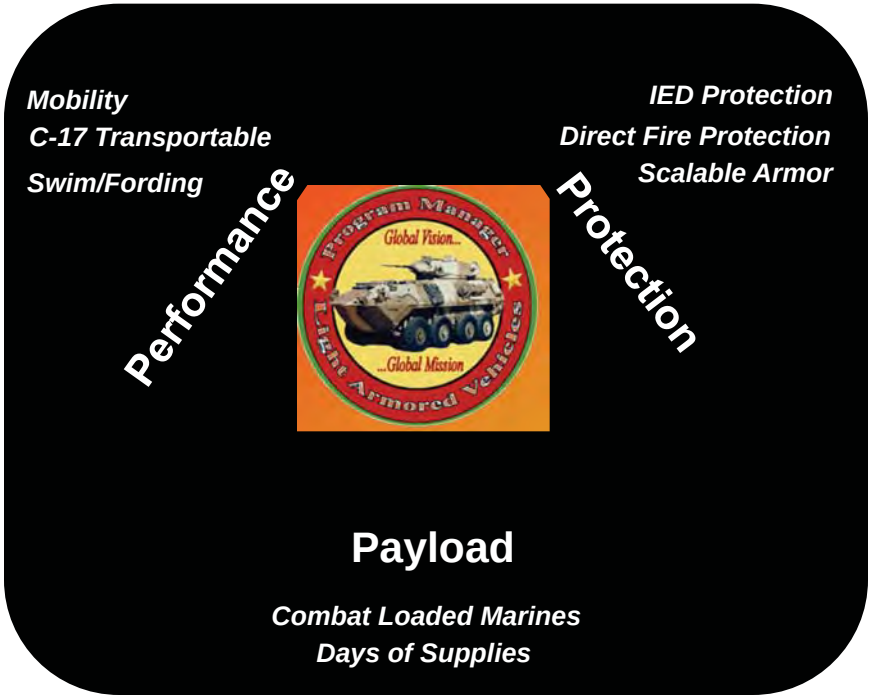
Decision-makers afforded novel real-time, panoramic view of trade-offs and parametric sensitivities via advanced visualization features

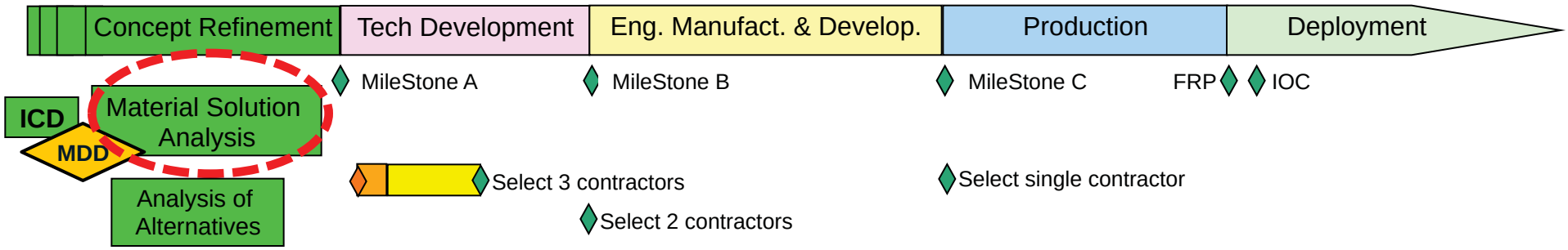
Research conducted on capability-focused and inverse design to identify solutions that meet dynamic requirements

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





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

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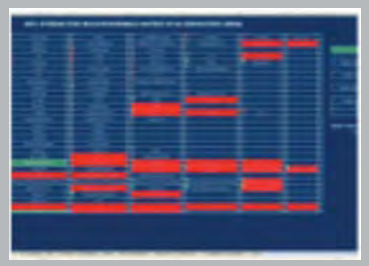
Sub-system Technology Selection Tool

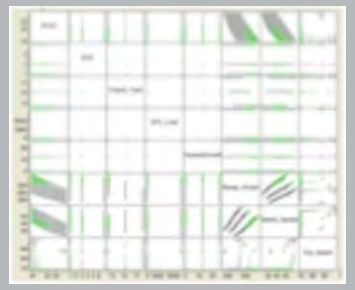


Compare and prioritize technology

Vehicle Performance Generation Tool (VPGT)

Generate valid design solutions

Statistical Data Analysis



Design space exploration

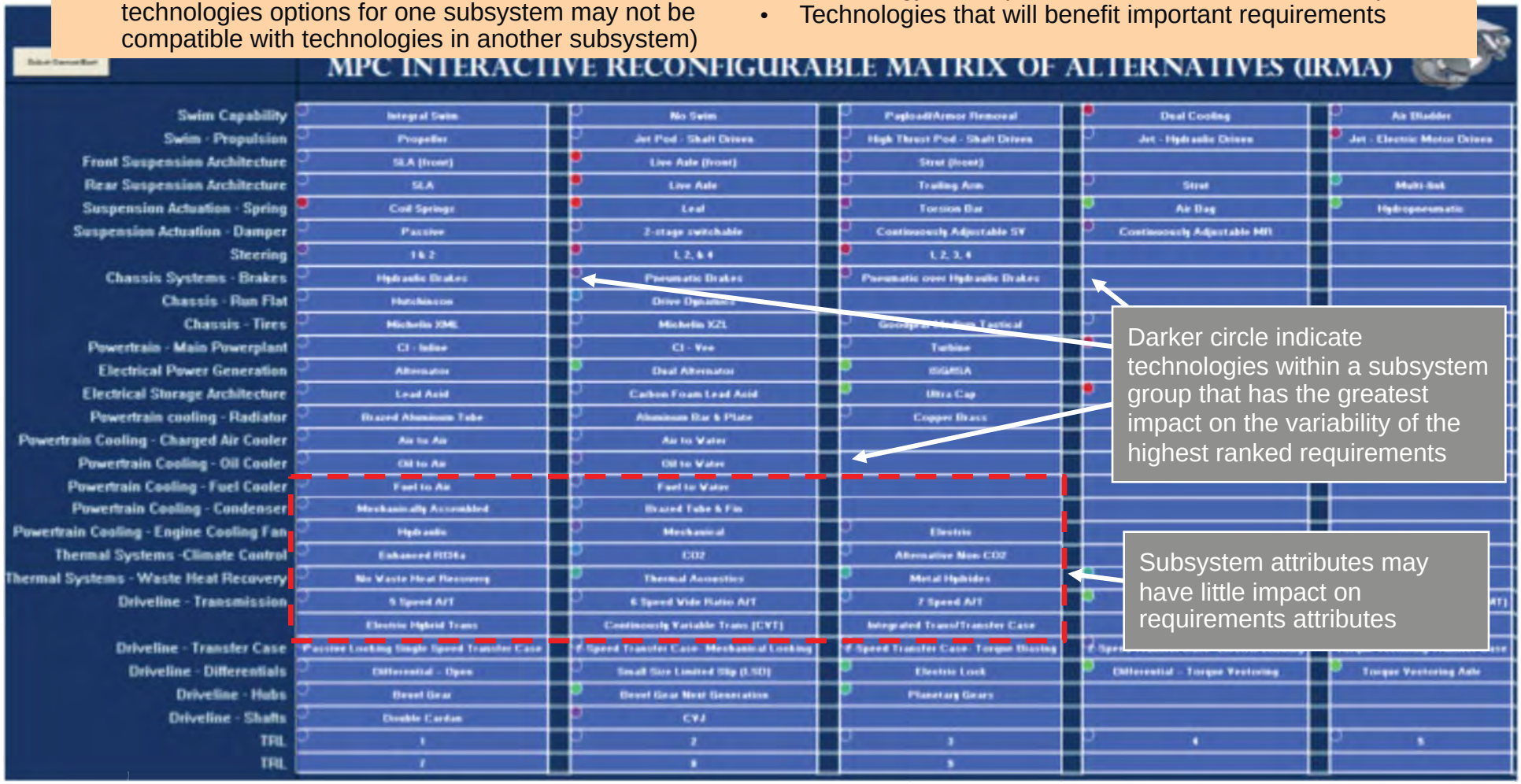
Vehicle Comparison Tool (VCT)

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



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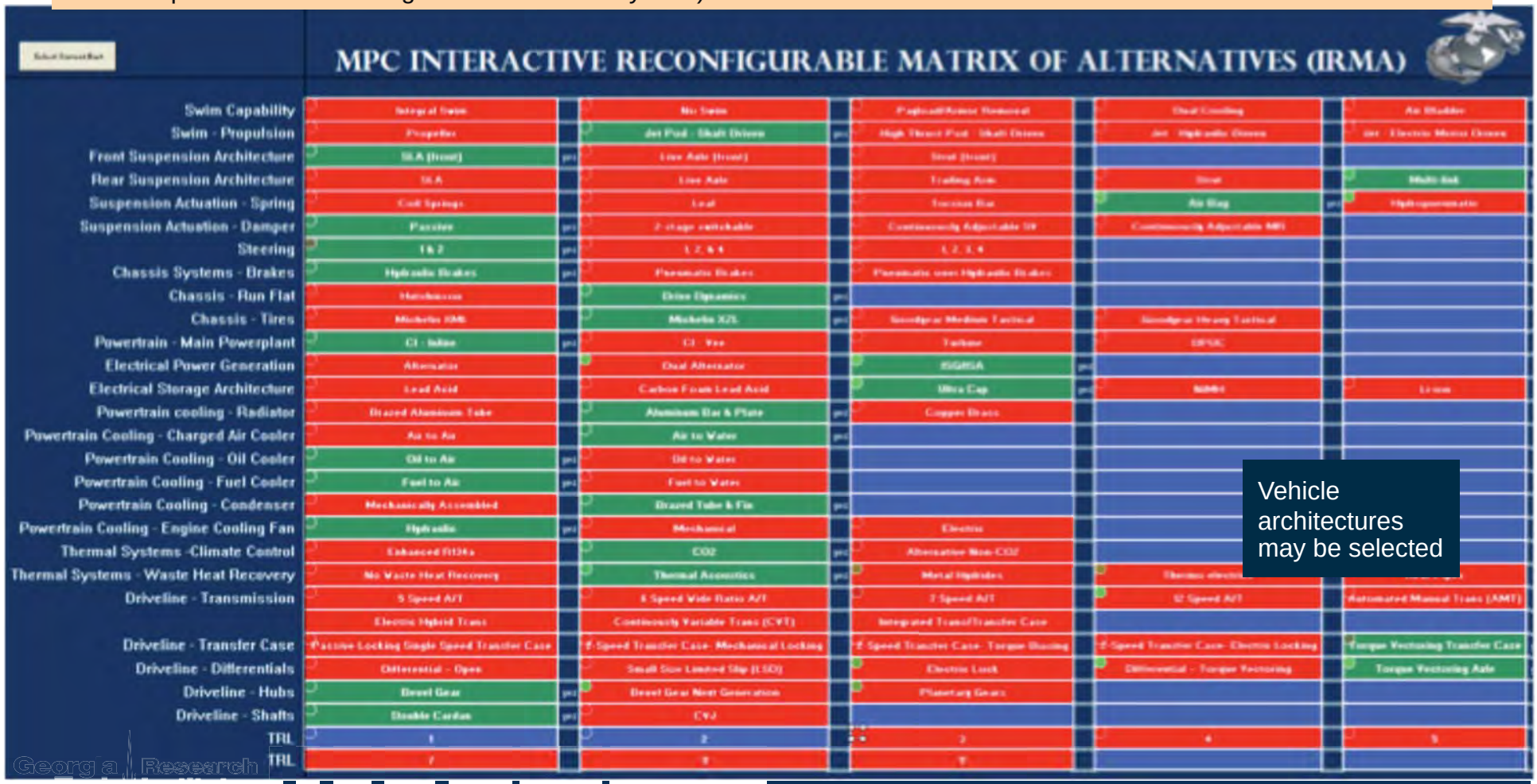
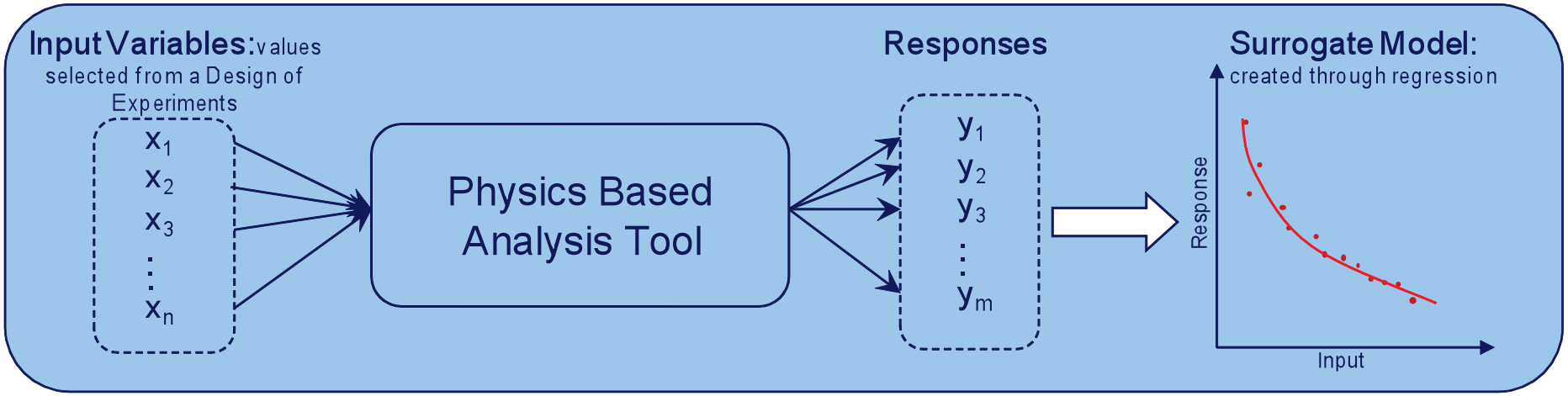


Surrogate models



Bringing Modeling & Simulation Forward in the Decision Making Process

MPC VEHICLE PERFORMANCE GENERATION TOOL

Configuration Inputs

Default Settings

Advanced Inputs/Outputs

Save/Load Vehicle

Export Vehicles to VCT

Armor Density Inputs

Save Custom Armor

Roof

Rear

Right/Left Sides

Nose

Belly

Transportability Results

	Air Transport	Ground Transport	Rail Transport	Inter-theater Shipping	Sea Connectors
Curb	C-17 Transportable	Does Not Meet			
Curb+2	C-17 Transportable	Does Not Meet			
Curb+X2	C-17 Transportable	Does Not Meet			
GVW	C-17 Transportable	Does Not Meet		Does Not Meet	Does Not Meet
GVWR	C-17 Transportable	Does Not Meet		Does Not Meet	Does Not Meet

Performance Results

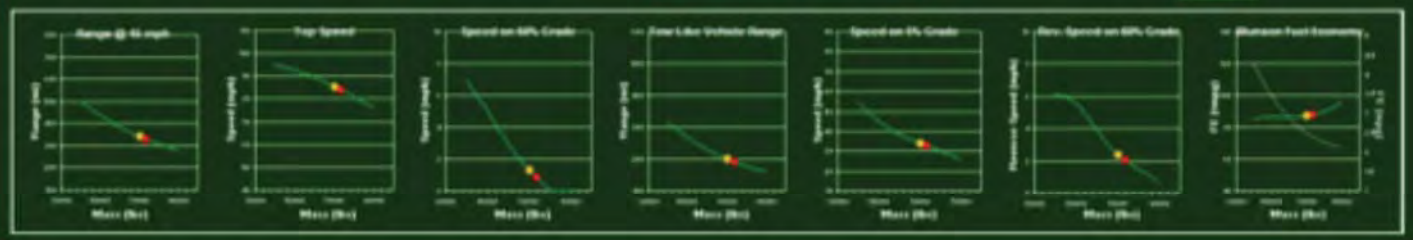
	Metric	Value	Threshold	Objective
At GVWR	Range at 45 mph (mi)	XX.XX	XX.XX	XX.XX
	Speed on 6% Grade (mph)	XX.XX	XX.XX	XX.XX
	Top Speed (mph)	XX.XX	XX.XX	XX.XX
	Sustained Cycle Fit (mpg)	XX.XX	XX.XX	XX.XX
	Speed on 60% Grade (mph)	XX.XX	XX.XX	XX.XX
	Reverse Speed on 60% Grade (mph)	XX.XX	XX.XX	XX.XX
	Tow Like Vehicle Range (mi)	XX.XX	XX.XX	XX.XX
	Maximum Side Slope Angle (deg)	XX.XX	XX.XX	XX.XX
	NATO Lane Change Speed (mph)	XX.XX	XX.XX	XX.XX
	Maximum Lateral Acceleration (g)	XX.XX	XX.XX	XX.XX
	10 Inch Half Round Speed (mph) at 2.5g	XX.XX	XX.XX	XX.XX
	12 Inch Half Round Speed (mph) at 2.5g	XX.XX	XX.XX	XX.XX
	1.0" RMS max Speed (mph) at XX	XX.XX	XX.XX	XX.XX
	1.5" RMS max Speed (mph) at XX	XX.XX	XX.XX	XX.XX
	2.0" RMS max Speed (mph) at XX	XX.XX	XX.XX	XX.XX
	2.5" RMS max Speed (mph) at XX	XX.XX	XX.XX	XX.XX
	2.7" RMS max Speed (mph) at XX	XX.XX	XX.XX	XX.XX
	3.74" RMS max Speed (mph) at XX	XX.XX	XX.XX	XX.XX
	MMMM Jordan Sand VSI	XX.XX	XX.XX	XX.XX
At GFV	MMMM Korea Wet VSI	XX.XX	XX.XX	XX.XX
	MMMM Germany Dry VSI	XX.XX	XX.XX	XX.XX
	MMMM VCI	XX.XX	XX.XX	XX.XX

Sensitivity Analysis

Sensitivity Parameter

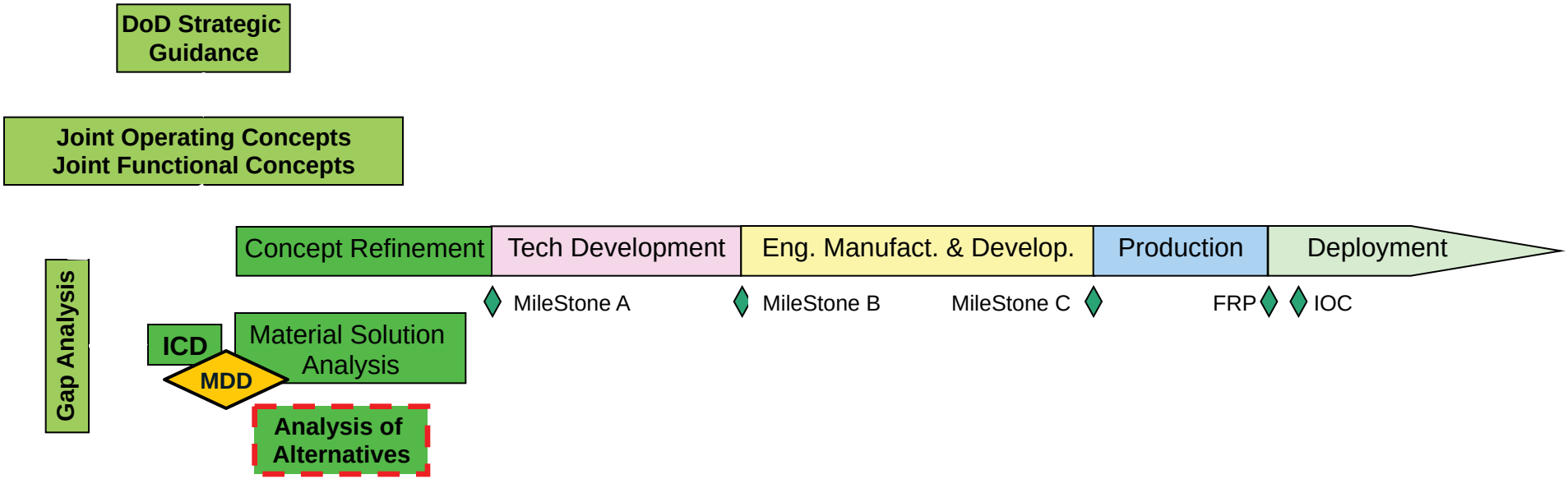
GVW

GVWR

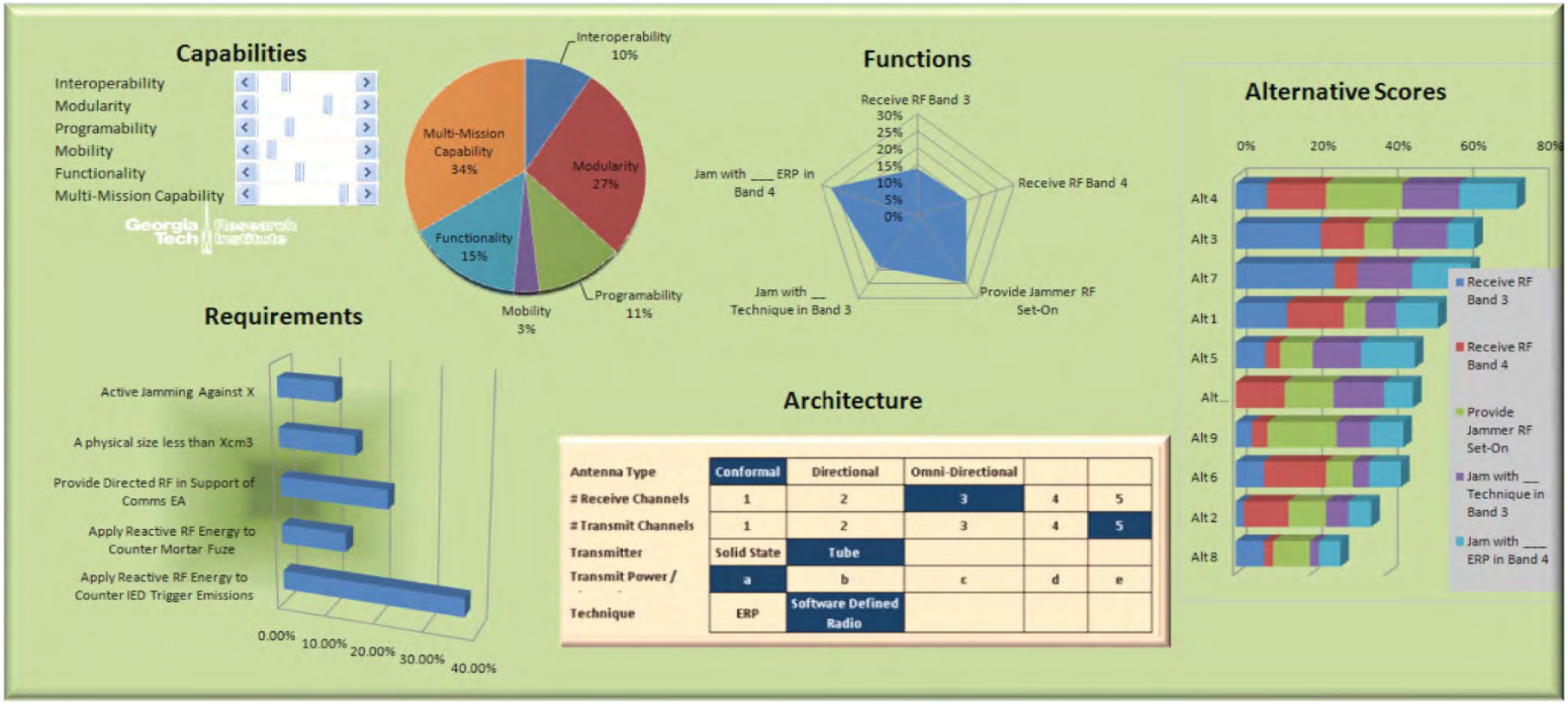


Mass and Geometry Results

Passenger Compartment Change vs.	
Length	0.00 in
Width	0.00 in
Height	0.00 in
Mass Data	
Curb	42384 lb
Curb+2	43284 lb
Curb+OCC	47477 lb
GVW	79178 lb
GVWR	72488 lb
Overall Vehicle Dimensions	
Length	23.46 ft
Width	8.84 ft
Height	7.91 ft



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


Capabilities
Interoperability
Modularity
Programability
Mobility
Functionality
Multi-Mission Capability
Georgia Tech Research Institute
Interoperability 10%
Modularity 27%
Programability 11%
Mobility 3%
Functionality 15%
Multi-Mission Capability 34%
Functions
Receive RF Band 3
Receive RF Band 4
Provide Jammer RF Set-On
Jam with __ Technique in Band 3
Jam with ___ ERP in Band 4
30%
25%
20%
15%
10%
5%
0%
Alternative Scores
0%
20%
40%
60%
80%
Alt 4
Alt 3
Alt 7
Alt 1
Alt 5
Alt...
Alt 9
Alt 6
Alt 2
Alt 8
Receive RF Band 3
Receive RF Band 4
Provide Jammer RF Set-On
Jam with __ Technique in Band 3
Jam with ___ ERP in Band 4
Requirements
Active Jamming Against X
A physical size less than Xcm3
Provide Directed RF in Support of Comms EA
Apply Reactive RF Energy to Counter Mortar Fuze
Apply Reactive RF Energy to Counter IED Trigger Emissions
0.00%
10.00%
20.00%
30.00%
40.00%
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 | | | |

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See also our work in RT21 and RT24

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SYSTEMS ENGINEERING Research Center

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: *http://www.pslm.gatech.edu/projects/incose-mbse-msi/*
- These publications: *http://eislab.gatech.edu/pubs/seminars-etc/2009-04-ndia-ms/*

Contact

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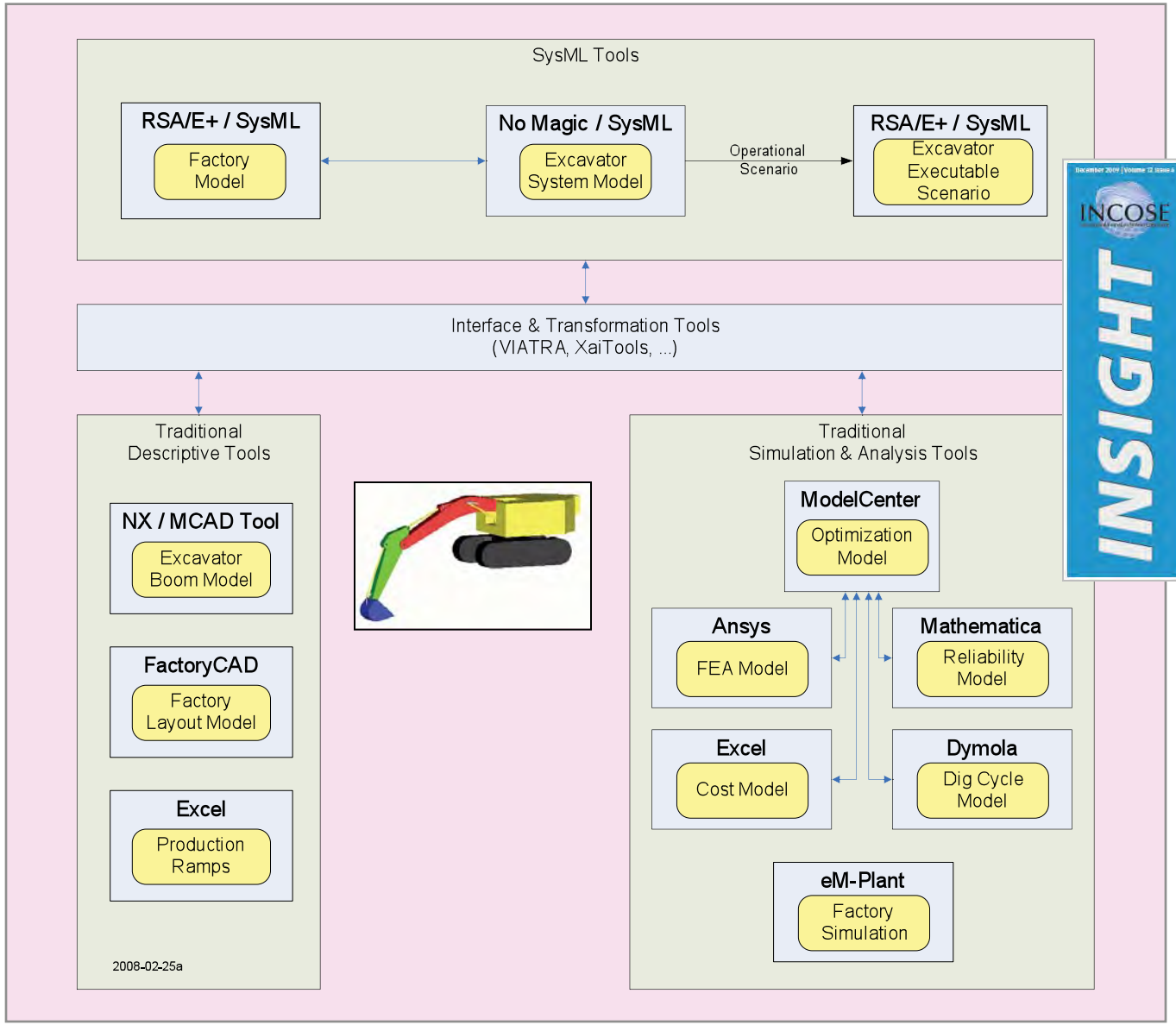
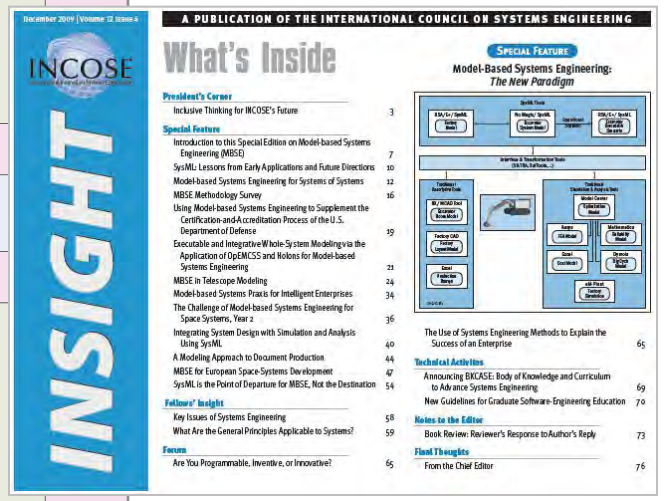
Excavator Modeling & Simulation Testbed

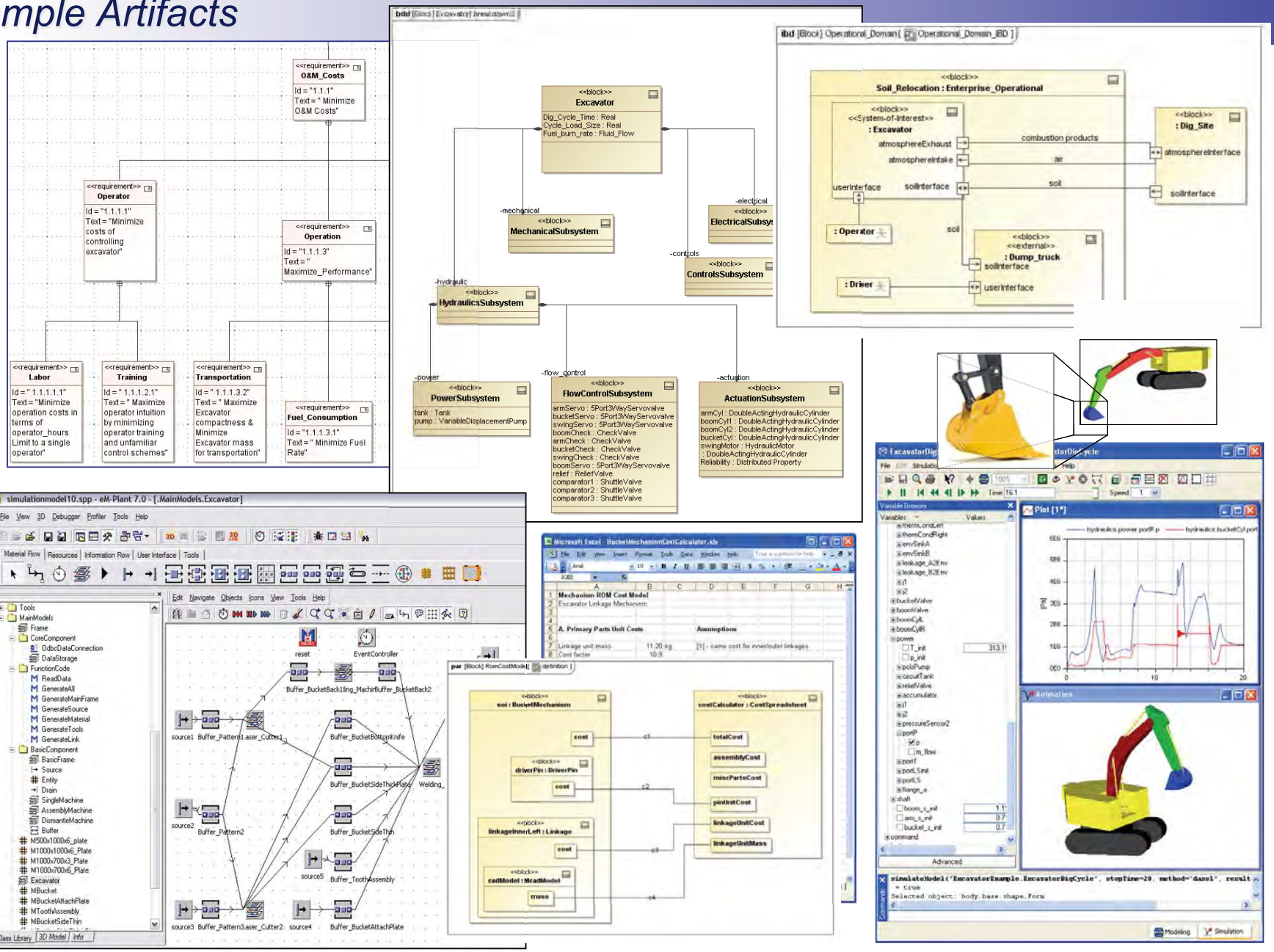
Tool Categories View





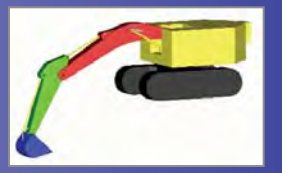
Excavator Modeling & Simulation Testbed

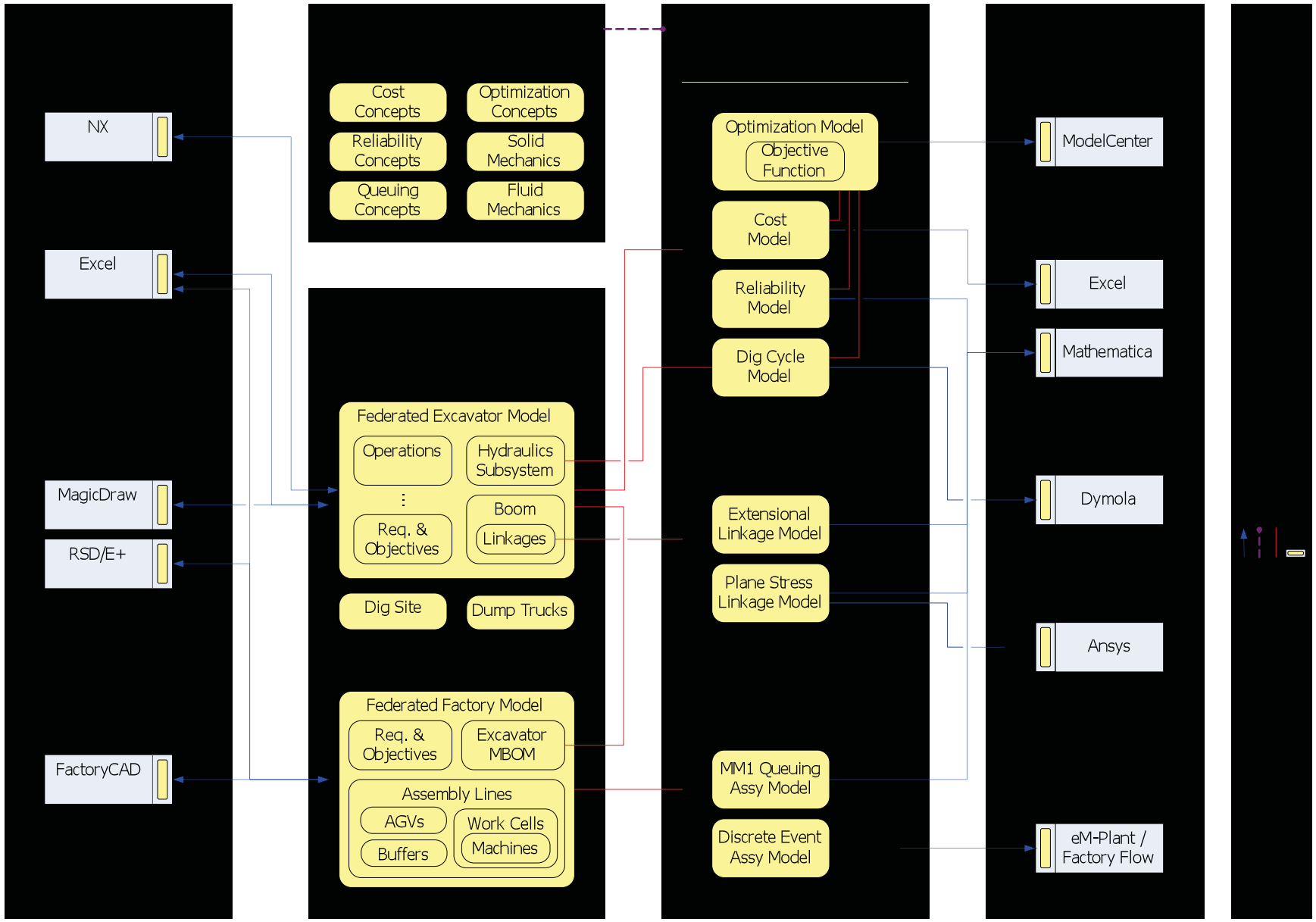
Sample Artifacts



Excavator Modeling & Simulation Testbed

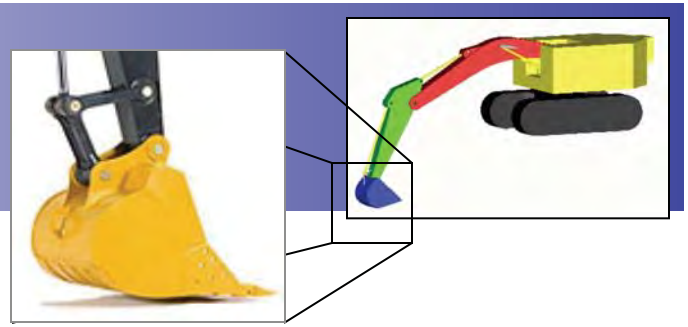
Interoperability Patterns View (MSI Panorama per MIM patterns)

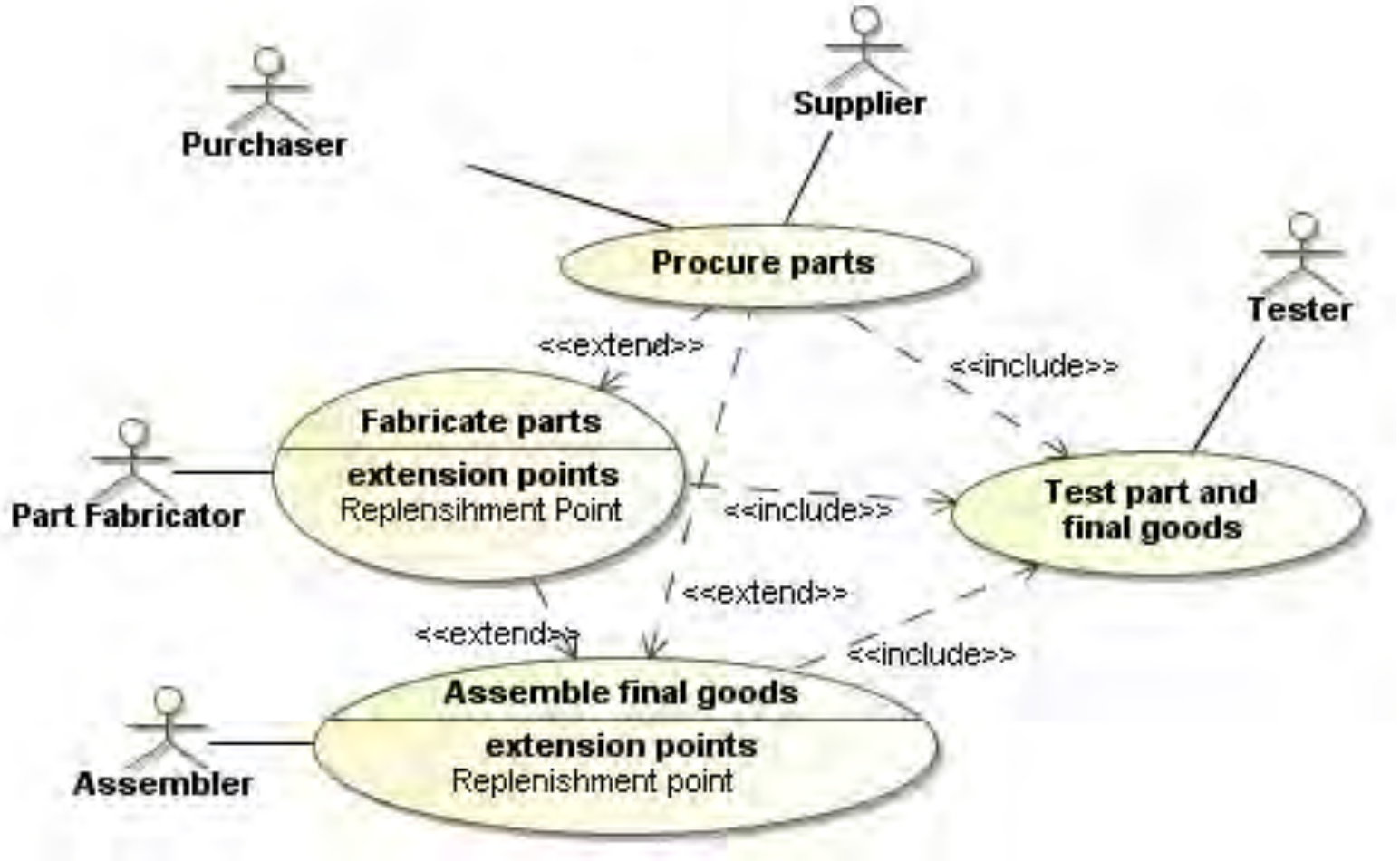




Manufacturing Use Cases

[McGinnis et al.]

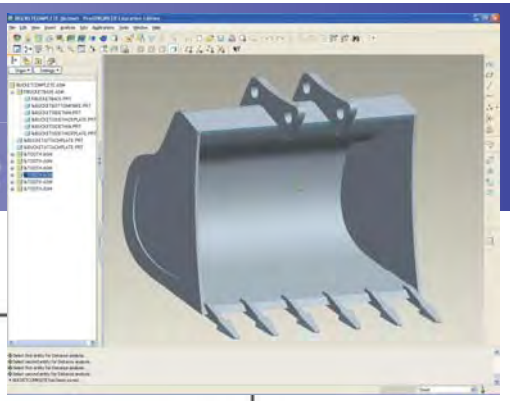


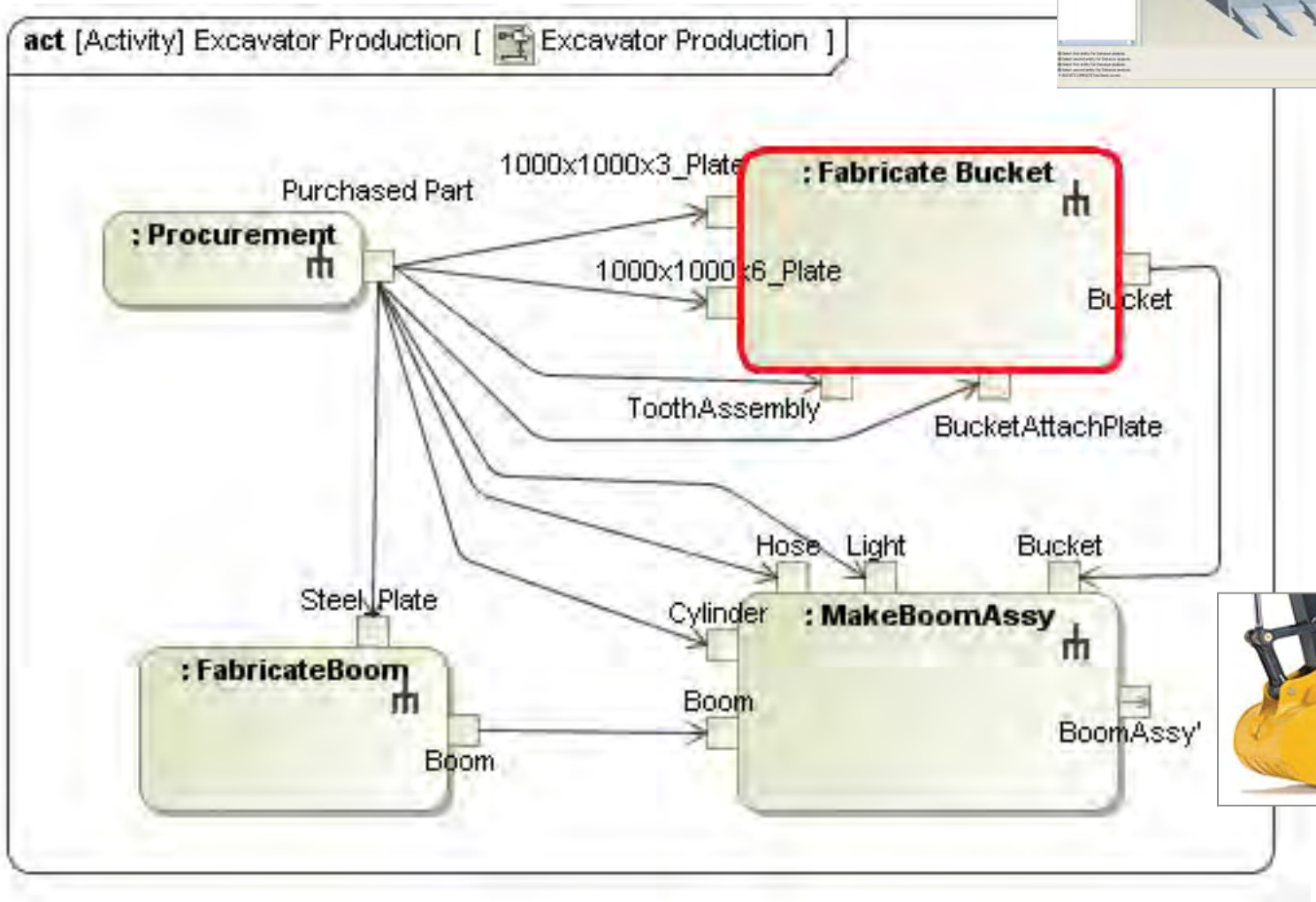


Process Planning Model

Functional modeling style using SysML activities

[McGinnis et al.]





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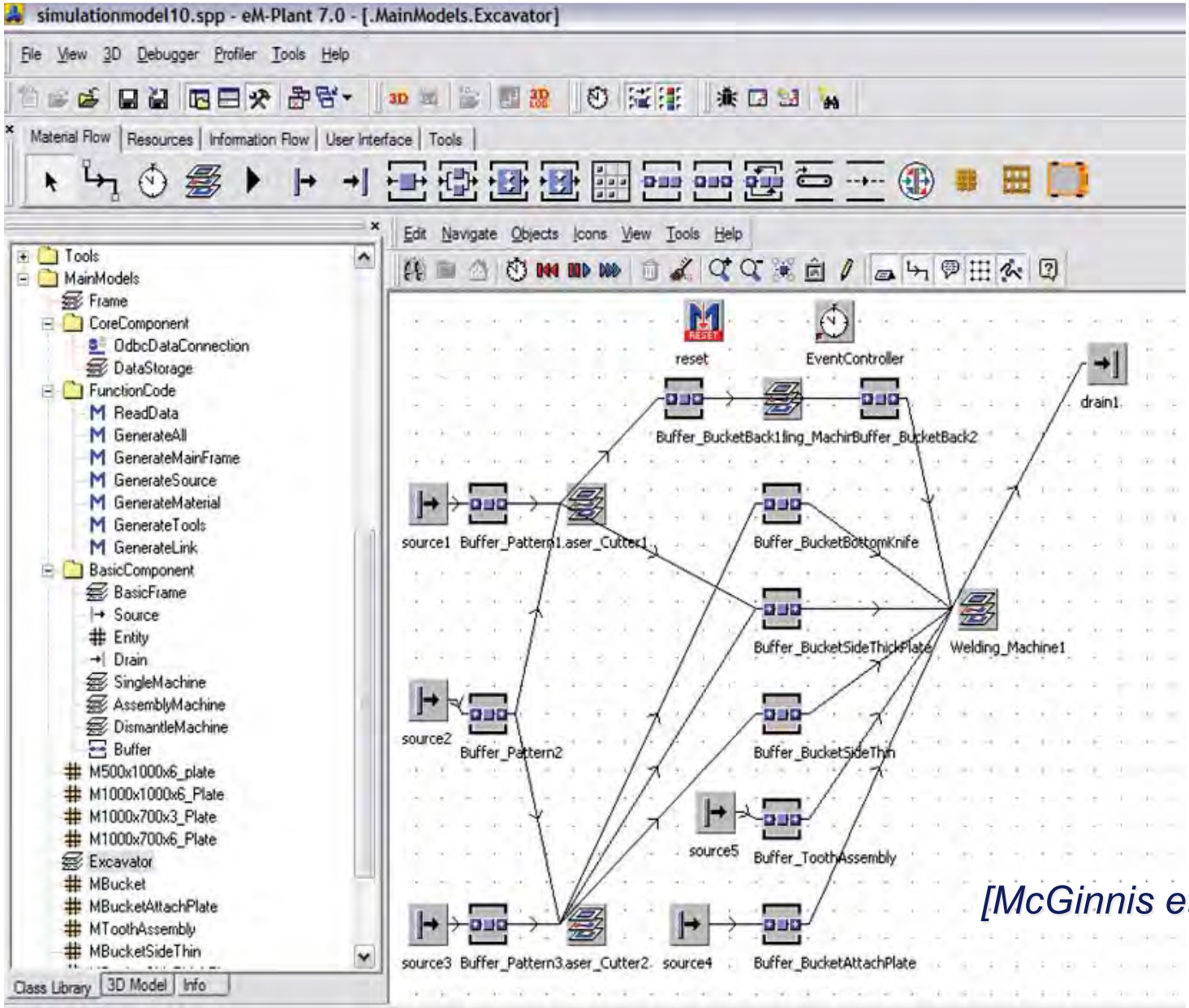
eM-Plant Simulation

Discrete event model auto-generated from SysML



[McGinnis et al.]

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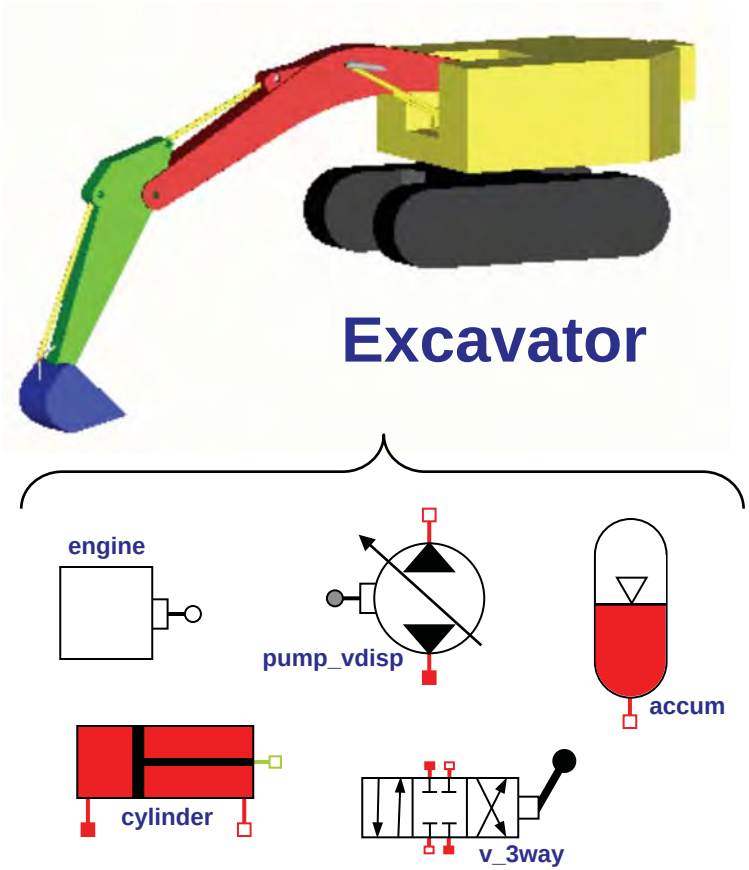
Exploration of System Architectures

CENTER FOR COMPACT AND EFFICIENT FLUID POWER

Problem Statement

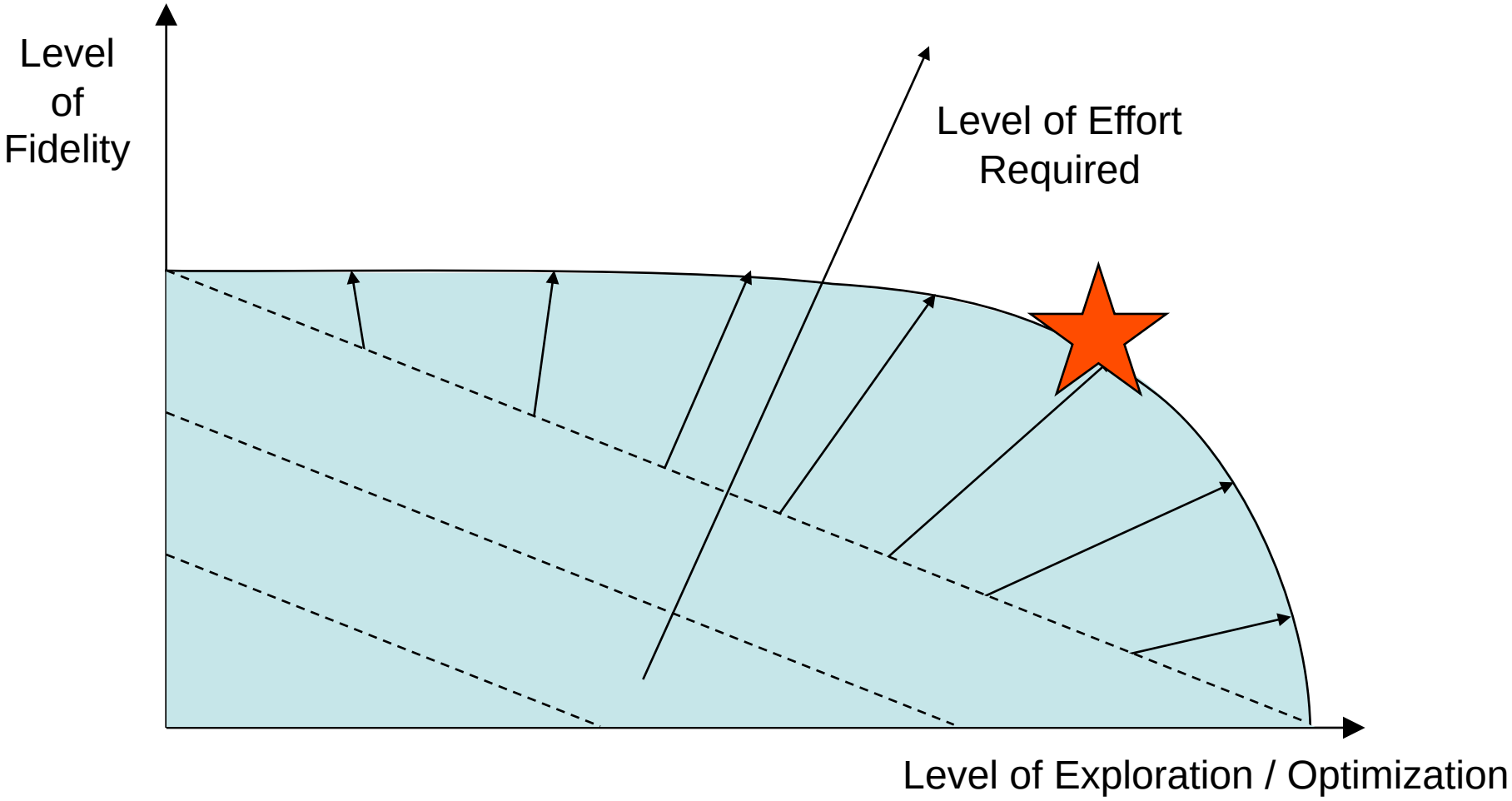
Given:
- Component models
- Objectives / preferences

Find:
- Best system architecture
- Best component parameters
- Best controller



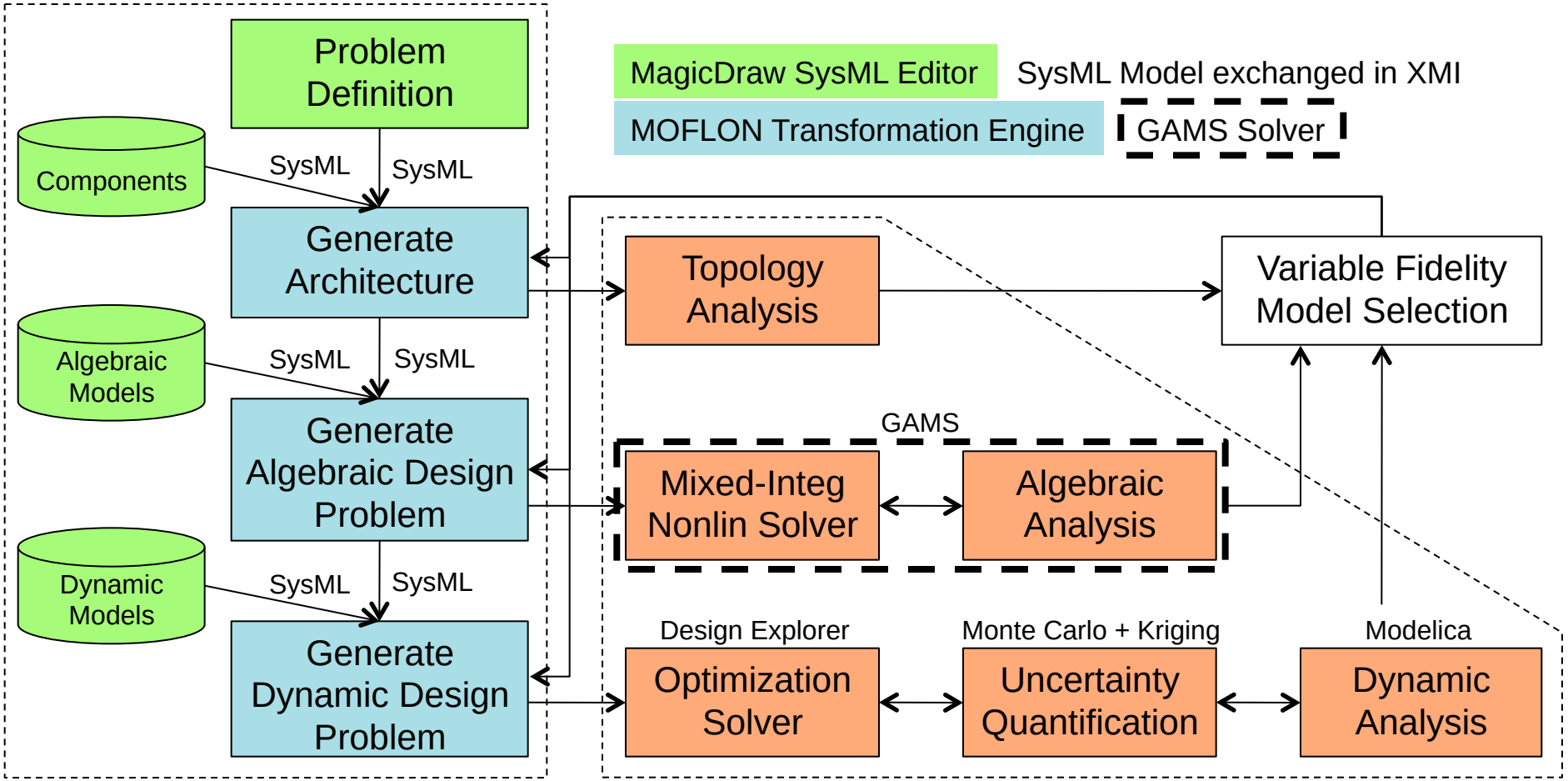
How to connect and size these?

Designer's Dilemma
M&S Risk/Benefit vs. Cost



Architecture Exploration Framework

CENTER FOR COMPACT AND EFFICIENT FLUID POWER



Both Problem Formulation and Problem Solution phases are implemented in ModelCenter

SysML Parametrics

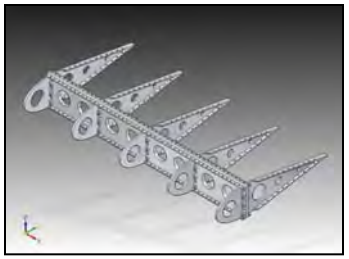
Peak et al.

- 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, ...

- Generic (shown)
- Wind turbine-specifics (not shown)

«block» **System**

-Cust 1..*

«block» **Customer**

-Cust_Prodn

-Cmpy

«block» **Company**

-Xport 1..*

«block» **TransportMode**

-Sup 1..*

«block» **Supplier**

-Prodn 1..*

«block» **ProductionSite**

-WH 1..*

«block» **Warehouse**

-SPrD 1..*

-SPrS 1..*

-BoM 1..*

«block» **SiteProductDemand**

-SPrD

«block» **SiteProductSupply**

-MB1

«block» **Model_BoM**

-SPrD1 1..*

-SPtS

1..*

-SPtS1 1..*

-Part_BoM 1..*

-Part 1..*

-WHPart 1..*

-SupPart 1..*

«block» **SitePartDemand**

«block» **SitePartSupply**

«block» **SKU**

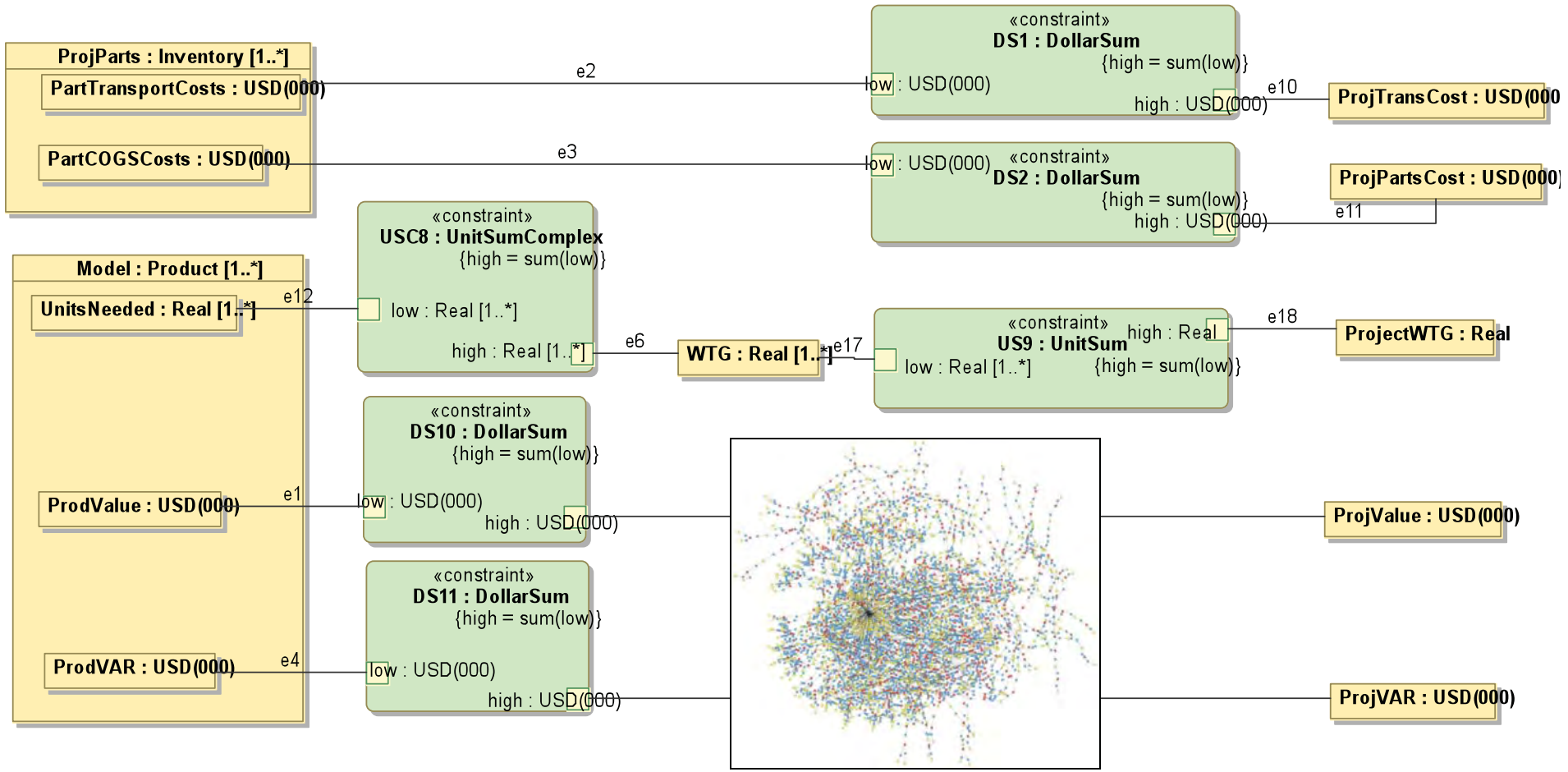
«block» **WarehousePart**

«block» **SupplierPart**

Supply Chain Model – SysML Parametrics

Connect to Optimization Models, Compute Value-at-Risk

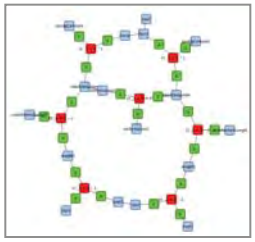
Ex. Given 100's of product orders and sourcing plans for the next 12 months, what percent of my business is at-risk if Supplier X does not deliver, or if Part Y becomes obsolete?



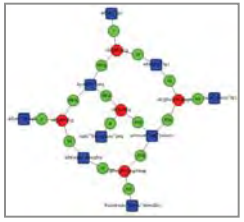
Model "DNA Signatures" Using SysML Parametrics

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

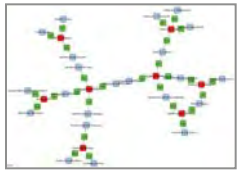
a. Snowman



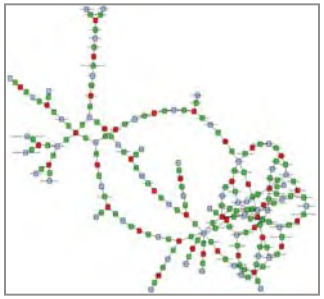
b. Mini Snowman



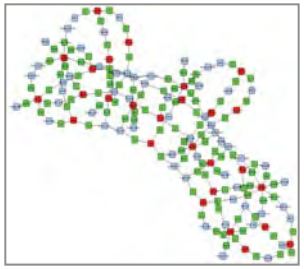
c. Snowflake



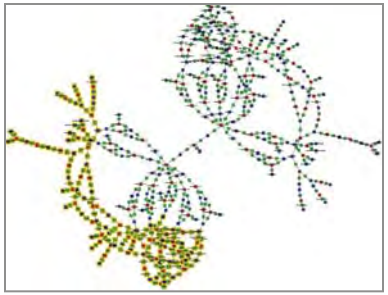
d. Mouse



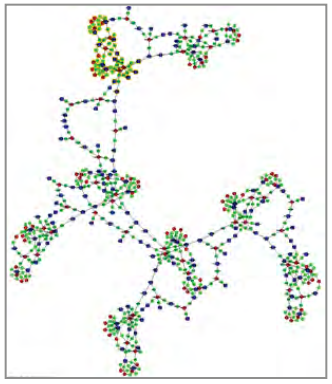
e. Cactus



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

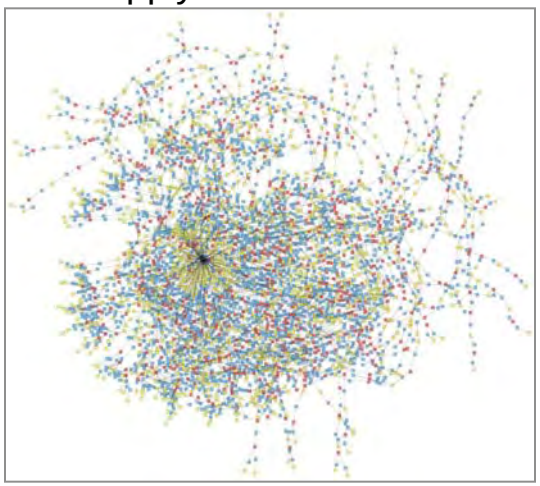
__b__ 5. Car gas mileage model

__d__ 6. Airframe mechanical part model

__f__ 7. Design verification model
(automated test for two Item 6. designs)

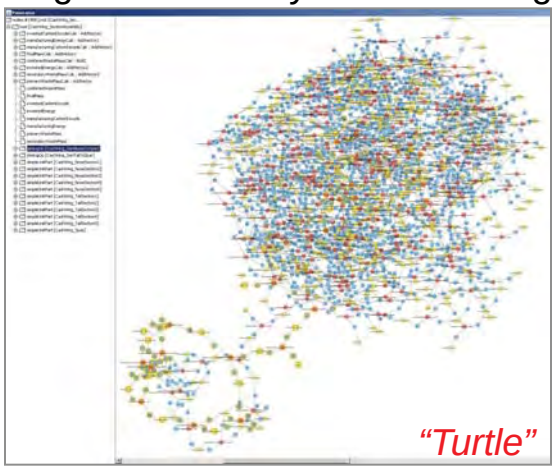
Recent Models: ~Medium Complexity

supply chain metrics



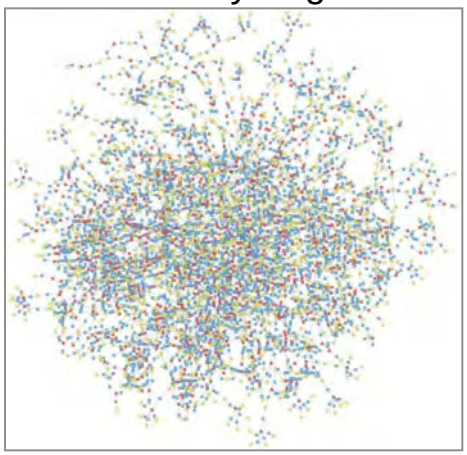
"Galaxy with Black Hole"

mfg. sustainability: airframe wing



"Turtle"

electronics recycling network



"Tumbleweed"

mfg. sustainability: automotive transmissions

"Turtle Bird"

"Angler Fish"

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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.
- Summary

See also our work in RT16 and RT25

See also our work in RT21 and RT24

Georgia Tech as part of SERC

SYSTEMS ENGINEERING Research Center

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

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