Overview of Systems Engineering Research at Georgia Tech

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(other main contributors)
### Overview of Systems Engineering Research at Georgia Tech

Presented at the 2nd Annual SERC Research Review Conference, 9-10 Nov 2010, College Park, MD. SERC is sponsored by the Department of Defense. U.S. Government or Federal Rights License

**Report Documentation Page**

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<td>Stevens Institute of Technology, Systems Engineering Research Center (SERC), 1 Castle Point on Hudson, Hoboken, NJ, 07030</td>
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**12. DISTRIBUTION/AVAILABILITY STATEMENT**

Approved for public release; distribution unlimited

**13. SUPPLEMENTARY NOTES**

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**14. ABSTRACT**

**15. SUBJECT TERMS**

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- a. REPORT unclassified
- b. ABSTRACT unclassified
- c. THIS PAGE unclassified

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**18. NUMBER OF PAGES**

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Standard Form 298 (Rev. 8-98)

Prescribed by ANSI Std Z39-18
Contents

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• 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
# Georgia Tech Fun Facts

<table>
<thead>
<tr>
<th>Year</th>
<th>Event</th>
<th>Details</th>
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<tbody>
<tr>
<td>1885</td>
<td>Founded</td>
<td>in Atlanta</td>
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<tr>
<td></td>
<td>Faculty</td>
<td>5 Professors, 5 Shop Supervisors</td>
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<tr>
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<td>Students</td>
<td>129 undergrads in Mechanical Engineering</td>
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<tr>
<td>1903</td>
<td>First full-time football coach</td>
<td>John Heisman</td>
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<tr>
<td>1948</td>
<td>Renamed</td>
<td>Georgia Institute of Technology</td>
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<td>1996</td>
<td>Served as Olympic Village</td>
<td>for 10,000+ athletes/staff</td>
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<td>Mascots</td>
<td>![Mascots Image]</td>
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Georgia Tech Statistics

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

engineering: ~11,000
• Introduction

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• Summary
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 format in SE certificate program (www.pe.gatech.edu)

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

SE Processes & Techniques
Integrated SE Mgt
SE Tools, Standards, Languages
Domain Specific Engineering
Complex Systems
• Introduction
• Selected SE-related efforts
  – Professional Masters in SE (PMASE) *Bishop, et al.*
  – Model-Based SE Center (MBSEC) *McGinnis, Paredis, Peak, et al.*
• Summary
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)

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

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

Knowledge and Skills for Enterprise Transformation.
Services

- 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

Requirements and designs are represented as information artifacts that evolve and change as they traverse processes
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
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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• Summary
Collaborative Decision Making

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
Marine Personnel Carrier (MPC)

- Mobility
  - C-17 Transportable
  - Swim/Fording
- IED Protection
- Direct Fire Protection
- Scalable Armor

Payload

- Combat Loaded Marines
- Days of Supplies

Optimization of the balance of performance, payload, and protection for the complete system.

Goal is to create achievable and affordable requirements in the aggregate before Tech Development (TD) phase.
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
The suite of tools are used together to allow the government to generate optimized performance targets.

**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

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
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
Surrogate models

Bringing Modeling & Simulation \textbf{Forward} in the Decision Making Process
Notional Integrated EW System (IEWS)

Acquisition Schedule

IOC
FRP
Tech Development
Eng. Manufact. & Develop.
Production
Deployment

MileStone A
Concept Refinement

MileStone B
MileStone C

Material Solution Analysis
ICD
MDD
Analysis of Alternatives

DoD Strategic Guidance

Joint Operating Concepts
Joint Functional Concepts

Gap Analysis

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

• Summary
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).

Citations

Contact
Russell.Peak@gatech.edu, Georgia Institute of Technology, Atlanta, www.msl.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, Xstools, ...)

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

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

Sample Artifacts
Manufacturing Use Cases
[McGinnis et al.]
Process Planning Model

Functional modeling style using SysML activities

[McGinnis et al.]

Diagram showing the process planning model with activities such as Procurement, Fabricate Bucket, Fabricate Boom, Make Boom Assy, and connections between different parts and activities.
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

Level of Exploration / Optimization

Level of Fidelity

Level of Effort Required

Chris Paredis
Architecture Exploration Framework

Components

Problem Definition

- MagicDraw SysML Editor
- MOFLON Transformation Engine

SysML Model exchanged in XMI

GAMS Solver

Generate Architecture

Topology Analysis

Variable Fidelity Model Selection

Generate Algebraic Design Problem

Mixed-Integ Nonlin Solver

GAMS

Generate Dynamic Design Problem

Optimization Solver

Uncertainty Quantification

Dynamic Analysis

Modelica

Both Problem Formulation and Problem Solution phases are implemented in ModelCenter
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, ...)

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Copyright © Georgia Tech and InterCAX. All Rights Reserved. SysML and MBSE.
SysML Model: Global Supply Chain Mgt. & Optimization

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

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

Sources: Dirk.Zwemer@InterCAX.com and Georgia Tech
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?
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
- mfg. sustainability: airframe wing
- electronics recycling network

- "Galaxy with Black Hole"
- "Turtle"
- "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
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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