Systems Engineering Research Center
Research Strategy and Progress

By
Barry Boehm
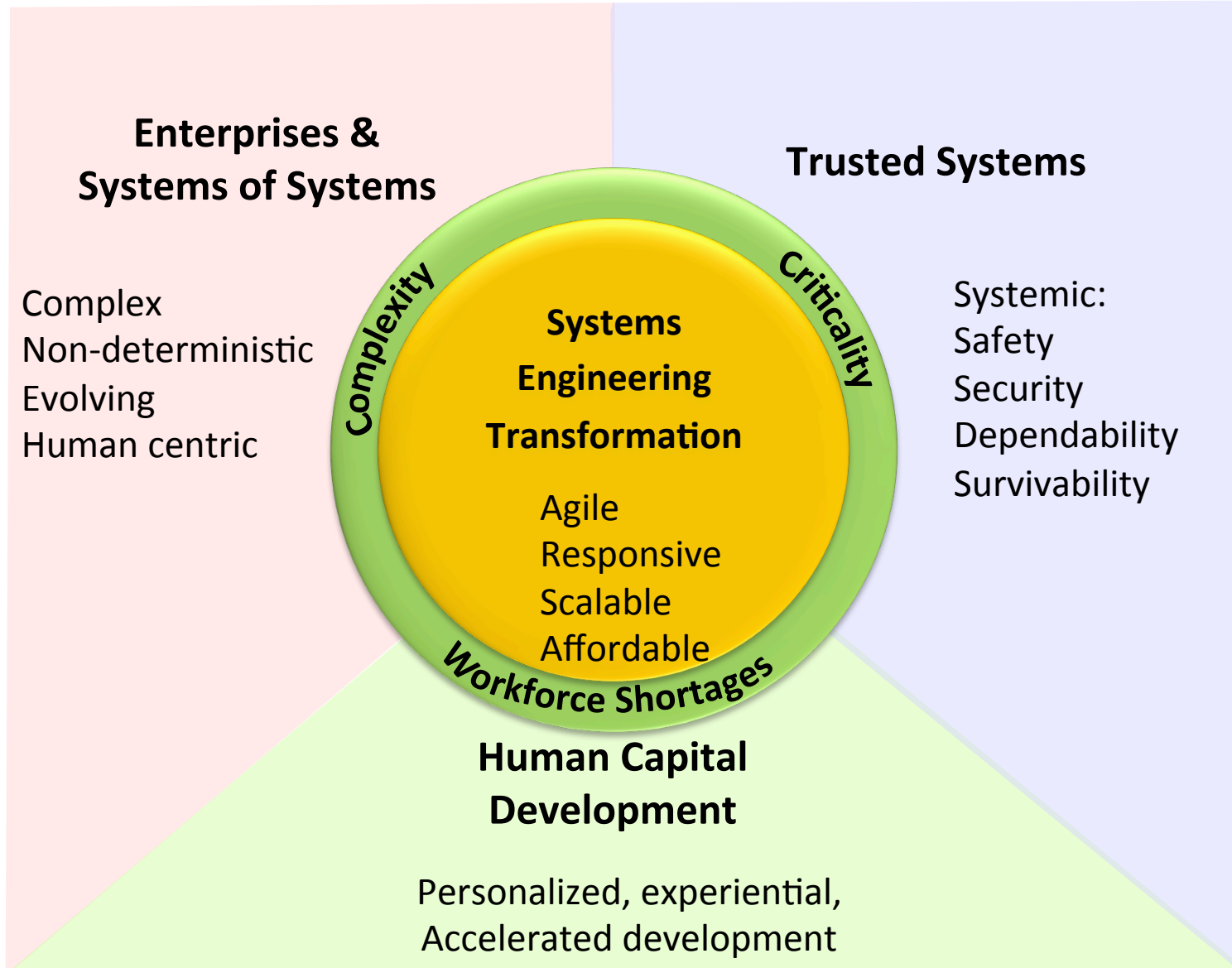**Director of Research**

Annual SERC Research Review
October 5-6, 2011
University of Maryland
Marriott Inn and Convention Center
Hyattsville, MD

www.sercuarc.org

SERC Research Strategy and Progress

- SERC Research Areas

- Research Strategy Elements and Progress
  - Exploit SE research strengths of 20 selected universities
  - Balance learning from the past with anticipating the future
  - Provide holistic SE research support of DoD S&T Emphasis Areas
  - Accelerate transition into practice

- Summary

SERC Research Areas

SYSTEMS ENGINEERING
Research Center

Enterprises & Systems of Systems

Complex
Non-deterministic
Evolving
Human centric

Trusted Systems

Systemic:
Safety
Security
Dependability
Survivability

Complexity

Criticality

Systems Engineering Transformation

Agile
Responsive
Scalable
Affordable

Workforce Shortages

Human Capital Development

Personalized, experiential, Accelerated development

Exploit SE research strengths of 20 universities

- Universities selected for DoD/IC SE research strengths
  —SE research track record
  —Familiarity and experience in working with DoD/IC organizations
  —Interest and capabilities in conducting multi-university research

- Open selection process for new-project performers
  —Clarify research objectives with sponsors
  —Use in call for ideas and related capabilities to all universities
  —Submissions and evaluation using tailored Heilmeier criteria
    o What's new? Why would it succeed? What difference will it make? Who cares? What are the costs, risks, and payoffs? What are the midterm and final "exams?"
  —Selection based on responses in coordination with sponsors

Learn from the Past; Anticipate the Future

- **Understand shortfalls in previous and current approaches**
  - Gather experience data and lessons learned

- **Understand, address future DoD/IC challenges and opportunities**
  - Asymmetric warfare: need rapid development and adaptation; resilience
  - Likely budget reductions: need affordable solutions, reliable autonomy
  - Net-centric, mobile systems of systems: need dynamic interoperability
  - New technologies: nanotech; smart systems; multicore chips; social networking; cloud services; massive data search; agile methods
  - Changing DoD workforce: less domain and SE experience; more ability to compose applications; trends in multitasking ability and attention spans
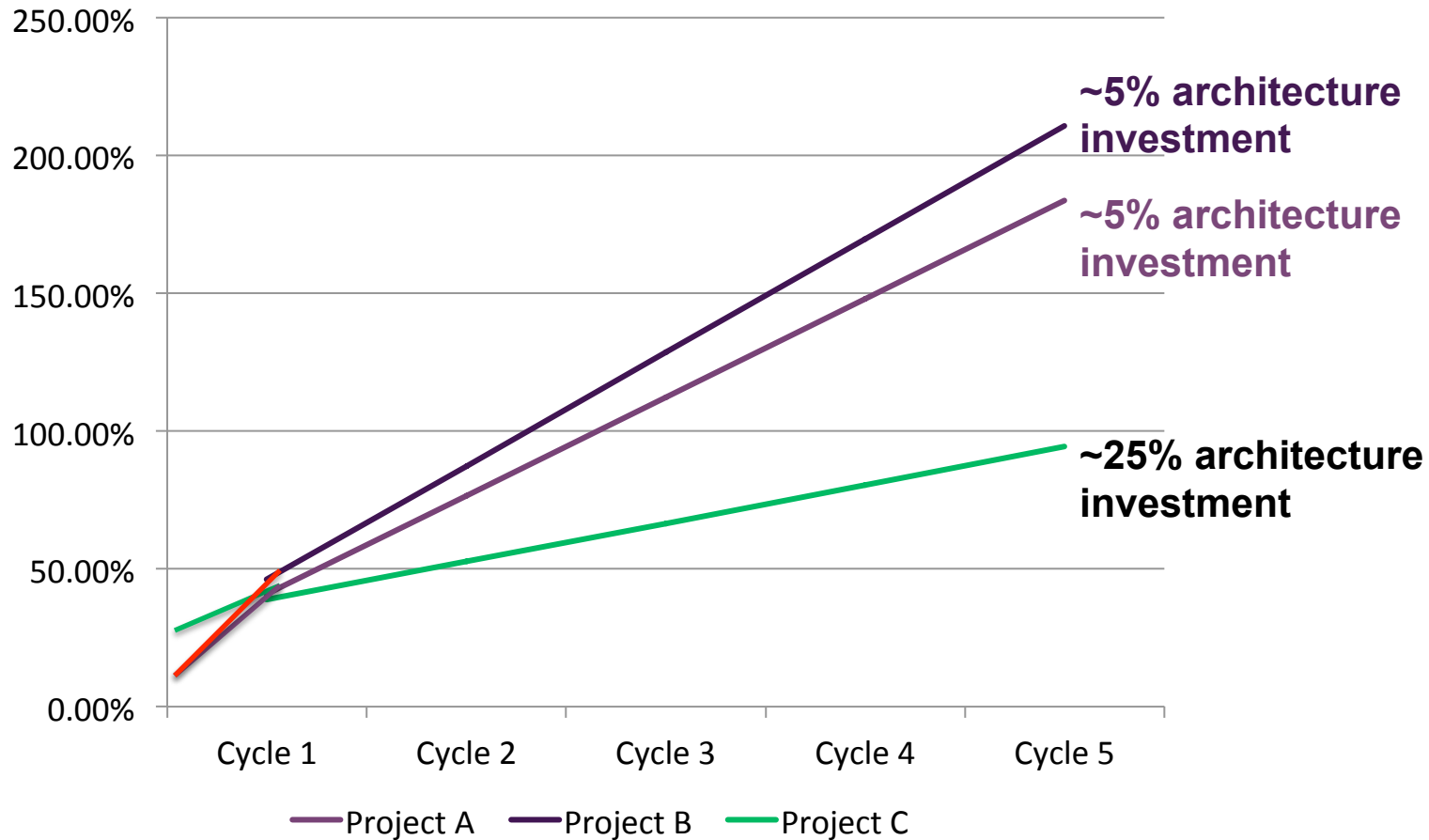
SE Research Support of DoD S&T Emphasis Areas

- **Autonomy and Human Systems**
  - —Need SE capabilities to balance both

- **Counter WMD; Electronic Warfare; Cyber Sciences**
  - —Need SE capabilities to detect threat; discriminate among threat classes; track and anticipate threat form; neutralize threat; assess effectiveness; adapt response; coordinate multiple threat responses

- **Data-to-Decisions**
  - —Need SE capabilities to define and migrate to open-systems architectures; perform tradeoffs among performance, false positives, and false negatives across a spectrum of representative operational scenarios

- **Engineering Resilient Systems**
  - —All about strengthening SE to address future challenges: more rapid, concurrent, and effective methods, processes, and tools; balancing resilience, mission effectiveness, and affordability

Balancing Autonomy and Human Systems

SYSTEMS ENGINEERING
Research Center

- Autonomy strengths
  - —Megasensor smart systems; decisions in microseconds; rapid adaptation; offload of human functions

- Autonomy challenges; need for human complement
  - —Autonomy failure modes: feedback instabilities; spoofing; rogue agents; V&V/debugging of self-modifying systems; commonsense reasoning

- Related SERC research
  - —Valuing flexibility: Effects of autonomy on total ownership costs; portfolio risk analysis of human-autonomy investments
  - —Rapid ConOps: Ability to visualize, explore complex decision options; human-adaptability of decision aids
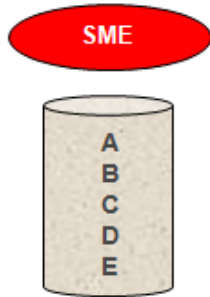
Relative* Total Ownership Cost (TOC)

~5% architecture investment

~5% architecture investment

~25% architecture investment

Legend: Project A — Project B — Project C

* Cumulative architecting and rework effort relative to initial development effort

Integrated Risk Management(IRM)
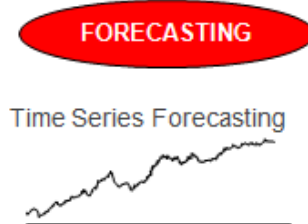
1 **List of projects and strategies**

RISK IDENTIFICATION

SME

A
B
C
D
E

Start with a list of projects or strategies to be evaluated... these projects have already been through qualitative screening
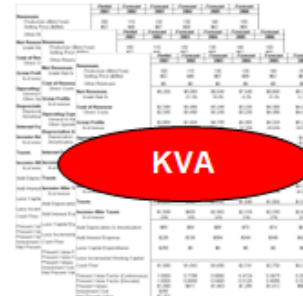
2 **Base case projections for each project**

RISK PREDICTION

FORECASTING

Time Series Forecasting

...with the assistance of time-series forecasting, future outcomes can be predicted...

3 **Develop static financial models**

RISK MODELING

KVA

Traditional analysis stops here!

...the user generates a traditional series of static base case financial (discounted cash flow) models for each project...

4 **Dynamic Monte Carlo simulation**

RISK ANALYSIS

RISK SIMULATION

Lognormal

...Monte Carlo simulation is added to the analysis and the financial model outputs become inputs into the real options analysis...
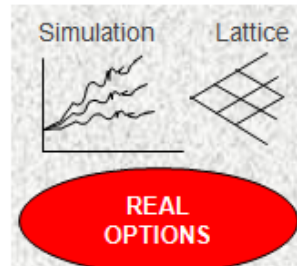
5 **Framing Real Options**

RISK MITIGATION

COA-AOA

...the relevant projects are chosen for real options analysis and the project or portfolio real options are framed...

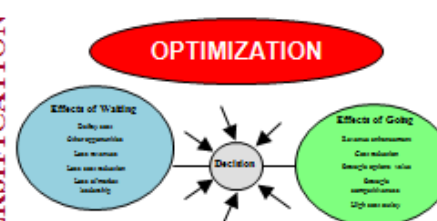**6** **Options analytics, simulation, optimization**

RISK HEDGING

Simulation   Lattice

REAL OPTIONS

...real options analytics are calculated through binomial lattices and closed-form partial-differential models with simulation...

7 **Portfolio optimization and asset allocation**

RISK DIVERSIFICATION

OPTIMIZATION

Effects of Waiting   Decision   Effects of Going

...stochastic optimization is the next optional step if multiple projects exist that require efficient asset allocation given some budgetary constraints... useful for strategic portfolio management...

8 **Reports presentation and update analysis**

RISK MANAGEMENT

UPDATES

...create reports, make decisions, and do it all again iteratively over time...

Running the model provides recommended selections

ACB 14 sample results with $150M budget constraint

Capability		Expected Military Value: SME Mean Value Added, DSLOC Complexity, Common Sized, Weighted OPNAV/Technical Priorities ▼				Selection of EMV calculation method

Capability		EMV	Cost	Risk $	Risk %	Selection
	Reset	37.68		$6.91	18.34%	0.0000
Capability		42.24		$3.81	9.03%	0.0000
Capability 1		19.78		$1.42	7.19%	0.0000
Capability 2		48.04		$2.77	5.76%	1.0000
Capability 3		21.07		$0.86	4.07%	1.0000
Capability 4		37.60		$5.90	15.68%	0.0000
Capability 5		48.05		$2.31	4.81%	1.0000
Capability 6		48.41		$3.34	6.89%	0.0000
Capability 7		20.07		$0.77	3.82%	1.0000
Capability 8		26.80		$1.62	6.03%	1.0000
Capability 9		18.78		$1.33	7.07%	1.0000
Capability 10		21.85		$2.48	11.37%	0.0000
Capability 11		22.15		$0.90	4.08%	1.0000
Capability 12		40.24		$3.85	9.56%	1.0000
Capability 13		14.77		$0.89	6.03%	1.0000
Capability 14		14.17		$1.16	8.16%	1.0000
Capability 15		27.10		$1.23	4.54%	1.0000
Capability 16		13.27		$0.49	3.72%	1.0000
Capability 17		9.54		$0.32	3.40%	0.0000
Capability 18		14.77		$0.24	1.64%	0.0000
Capability 19		15.67		$0.71	4.54%	0.0000
Capability 20		13.38		$0.63	4.68%	0.0000
Capability 21		9.23		$0.56	6.03%	0.0000
Capability 22						
Capability 23						

(Actual Capabilities Redacted — Cost Data Redacted)

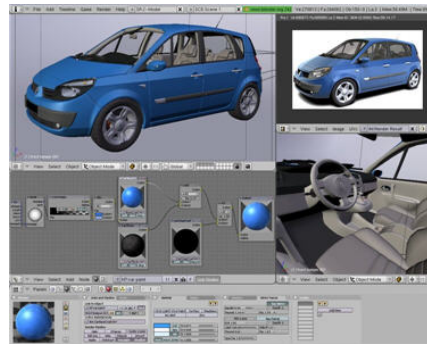| **Max EMV**	Total Constraints:	314.51	$150.00	$6.18		
		MAX	$150.00			

Go or No-Go decisions in the portfolio selection
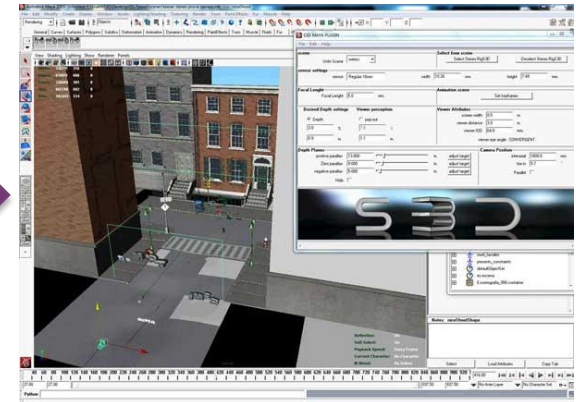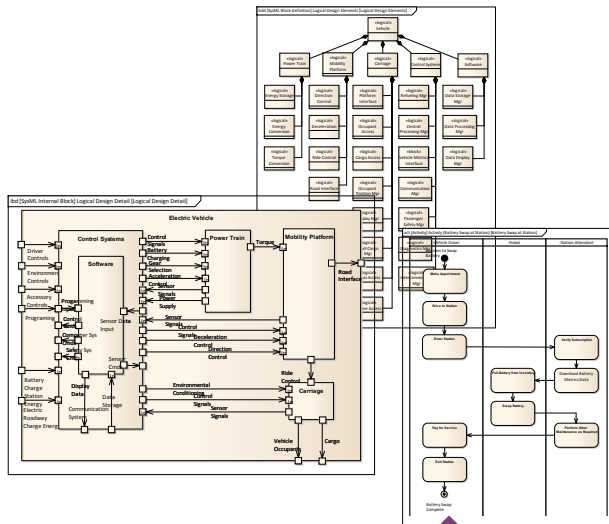
Benefits (EMV), Cost, Risk are considered

Constraints can be set (budget, capability count, FTE, priorities, etc)

Starting with 23 capabilities (more to be added later when there is sufficient data)

10

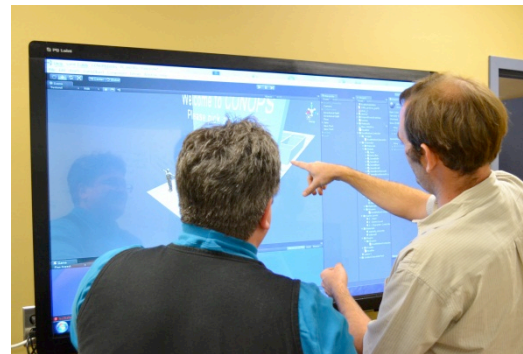SYSTEMS ENGINEERING
Research Center

Now we take those composed systems, and integrate them into a scenario fragment

Results are fed back to the model, updated, and run again

Collaborators are able to execute the scenario, and make adjustments

Complex System Architecture Decision Aid

- From RT-25, Requirements for Net-Centric Enterprises

- Emphasizes concurrent engineering of requirements and solutions

- Identifies relative strengths of architectural styles for common capability requirements

- Enables top level filtering of solution options

Integration styles vs. Properties	Topology				Linkage				Connector			
	Point-to-Point	Hub and Spoke	Shared Bus	Peer-to-Peer	Shared Data	Messaging	Explicit invocation	Data Streaming	Adapter	Translator	Arbitrator	Distributor
Distributed	o	+	+	+	o	+	+	+	o	o	+	+
Local	o	-	+	-	+	o	+	+	o	o	o	-
Secure	+	-	o	+/-	-	o	o	o	o	o	+	-
Data intensive	+	-	-	+	+	-	o	+	o	-	+	+
Data formats incompatible	o	+	o	-	-	+	o	o	o	+	o	o
Data consistency	o	+	o	-	+	o	o	-	o	o	+	o
Interaction protocols incompatible	o	+	o	-	+	o	-	o	+	o	o	o
Reliable	+	-	+	+	-	+	+	o	o	o	+	o
Real time	+	-	+/-	-	+	-	+	+	o	o	+	o
One-to-many	-	+	+	+	+/-	+	-	+	o	o	+	+
Many-to-one	-	+	o	+/-	o	+	-	o	o	o	+	+
Always available	+	-	o	+	-	+	o	o	o	o	+	o
Periodically scheduled	+	o	o	-	o	o	o	o	o	o	+	o
Loose coupling	-	+	+	+/-	-	+	-	-	+	+	+	+
Robustness	-	-	+	+	-	+	+/-	-	o	o	+	+
Dynamically reconfigurable	-	o	+	+	o	+	+	o	+	+	+	o
Scalable	-	-	+	+	-	+	o	o	o	o	+	+
Caching	-	+	+	o	+	o	-	-	o	-	+	+
Distributed transactions				+/-	+	+	+	o	o	o	+	+

Integration Styles Matrix in Action

Integration styles vs. Properties	Topology				Linkage				Connector			
	Point-to-Point	Hub and Spoke	Shared Bus	Peer-to-Peer	Shared Data	Messaging	Explicit invocation	Data Streaming	Adapter	Translator	Arbitrator	Distributor
Distributed	o	+	+	+	o	+	+	+	o	o	+	+
Secure	+	-	o	+/-		o	o	o	o	o	+	-
Data intensive	+	-	-	+	-	-	o	+	o	-	+	+
Data consistency	o	+	o	-	+	o	o	-	o	o	+	o
Reliable	+	-	+	+	-	+	+	o	o	o	+	o
Real time	+	-	+/-	-	+	-	+	+	o	o	+	o
Robustness	-	-	+	+	-	+	+/-	-	o	o	+	+
Distributed transactions	-	+	+	+/-	+	+	+	o	o	o	+	+
Positive (+)	4	3	4	4	3	4	4	3	0	0	8	4
Neutral (o)	2	0	2	0	1	2	3	3	8	7	0	3
Negative (-)	2	5	1	2	4	2	0	2	0	1	0	1
Positive / Negative (+/-)	0	0	1	2	0	0	1	0	0	0	0	0
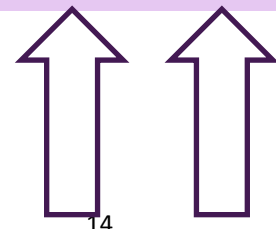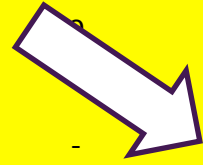
Messaging good for certain tasks, but to be avoided when transferring the data

Summary

- SERC concept of collaborative, multi-university SE research working in practice

- Some powerful general SE methods, processes, and tools are emerging
  — Enable more thorough consideration of tradeoffs among desired capabilities, such as in DoD S&T Emphasis Areas

- Just a few highlighted here; quite a few more to see and explore in next two days

- We are looking forward to feedback from potential users

Backup Charts

SERC Research Portfolio

Enterprises as Systems and Systems of Systems	
PROJECT	**DESCRIPTION**
Software Intensive Systems Data Quality and Estimation Research In Support of Future Defense Cost Analysis	Create improved ways to cost complex software-intensive systems, especially systems of systems Phases I and II
Requirements Definition for Net-Centric Enterprises	Prototype a method and tooling to support emerging requirements for net-centric enterprises Phases I and II
Contingency Basing	Develop new ways to do trade space analysis with application to Army contingency base planning
SOS Disruptions	Assess the Impact of Development Disruptions and Dependencies in Analysis of Alternative of System of System SoS
SOS Analysis and Architecting	An Advanced Computational Approach to System of Systems Analysis & Architecting using Agent-based Behavioral Modeling
Trusted Systems	
Security Systems Engineering Roadmap	Create a roadmap of research on security SE and begin executing that roadmap
Security Engineering	Develop and trial architectural patterns to enhance security
Human Capital Development	
Graduate SE Body of Knowledge and Reference Curriculum	Create a mature SE body of knowledge and guidance to construct a graduate program in SE Increments I, II, III
SE Technical Leadership Development	Create new ways to educate SE technical leaders more rapidly and effectively Phase I, II
Developing SE Experience Accelerator Prototype and Roadmap	Significantly reduce the amount of time it takes for a systems engineer to become proficient Years 1, 2
Research on Building Education and Workforce Capacity in SE	Research new ways to integrate SE into the education of all engineering students, emphasizing DoD-relevant problems Phase I, II
Vehicle Systems Engineering and Integration Activities	Determine competencies and capabilities needed for vehicle systems engineering
Systems Engineering Assessment & Workforce Development Plan	

SYSTEMS ENGINEERING
Research Center

Systems Engineering and Management Transformation	
PROJECT	**DESCRIPTION**
Early Identification of SE-Related Program Risks	Explore early identification of SE-related program risks
Evaluation of Agile SE MPTs on DoD/IC Programs	Explore agile MPTs with a focus on those applicable to the IC
Modular Reconfigurable Architecture for Tailored and Rapid SE Knowledge Dissemination	Create a new way to rapidly publish and maintain currency of SE artifacts and other documents, extensively tailoring them to audience
Rapid CONOPS Development Environment for Agile SE	Develop a new approach to quickly construct a CONOPS that strongly informs all key stakeholders and can evolve quickly and easily
Life Cycle SE Needs for Evolutionary SE	Create an MPT for evolutionary SE for acquisition in the context of 5000.02 and emphasis on early SE prior to Milestone B
Systems Engineering Transformation Roadmap	Create a research roadmap to transform SE into a more agile, responsive discipline that effectively leverages new technologies
System Maturity Assessment	Explore the equivalent of technology readiness levels, but for systems integration and other facets of engineering maturity
Valuing Flexible Systems	Develop architectural and other approaches to enable flexible systems
Phase I and II
Verification, Validation and Accreditation (VV&A) using Modeling and Simulation	Explore ways to perform "built-in" VV&A when creating system models and running system level simulations
DoD Systems 2020	Explore what new SE capabilities should be developed that enable creating systems more quickly and more flexibly, and that are more adaptable than traditionally possible. New phase with Stevens' lead
Communications Effects Server Model for SE Research	Establish systems architecture modeling and assessment environment with the Army's communications effects server
Integration of Modeling and Simulation, Software Design, and the DoD Architecture Framework	Integrate activities and artifacts of modeling and simulation, software design, and architecture
System Maturity and Architecture Assessment Methods, Processes and Tools	Show how to correlate SE architectural artifacts to system maturity assessments
Expedited SE	Develop and pilot ways to conduct SE much more rapidly while delivering full value
Agile – Lean SE	Develop a framework for agile-lean SE based largely on industry best practice

Vision

The networked national resource to further systems research and its impact on issues of national & global significance

Mission

Harness community of research talent through collaboration
Build tomorrow's community through research & education
Transition systems research to people, practice and impact
Influence cost conscious timely solutions through systems thinking
Enhance security and prosperity in the whole of the nation

KPI's

1. # of Society Fellows and Nat. Academy members
2. # of government and industry partnerships
3. Amount of multi-year funding
4. PhD and MS graduates
5. # of articles, papers, chapters, and books
6. Sponsor satisfaction
7. Impact on sponsor enterprises

Leverage Factors

Collaborators' Standing

Collaborators' Faculty, Students & Facilities

Collaborator Network

Relationship Network (Ind., Gov't & Acad.)

NAE & CESUN, INCOSE and others

Publications, Presentations and other outreach

Community Leadership

Strategies

Create Research Ecosystem

Develop Critical Sponsor Relationships

Conduct Transformational Research

Transition Results into Impact

Key Initiatives/Activities

1. Catalyze Community Growth
a) Build Partnerships
• Federal Agencies (DoD, FAA, DHS, etc.)
• Collaborator Network
• Other UARCs and FFRDCs entities
• Industries and Associations
b) Incentivize Involvement
• Fellowships, internships and mentoring
• Professional networking
• Community leadership
2. Accelerate SE Competency Development
Broaden Communication
• Strategic communications and branding
• Articles, papers, chapters & books
• Conferences, seminars & workshops
• SERC Journal, website & blogs
• Translation of research to curriculum and training
• Publication and usage of MPTs, case studies and lessons learned
3. Transform SE practice throughout the government
a) Invest in Infrastructure
• Modeling and simulation
• Enterprise Technologies
• Data sets and tools
• Visualization
• Collaboration venues
• Strategic communications
b) Create Transformation Capabilities
• Domain knowledge
• Enterprise architectures
• Methods and tools
• Best practices & education

DRAFT

Inspired by Tennenbaum Institute, Georgia Tech (Bill Rouse)