A Hands-on Approach to System Engineering Training and Development:

The Early Career Advanced Systems Project

T. Massey
R. Kennedy

The Johns Hopkins University
APPLIED PHYSICS LABORATORY

Agenda

- Need for Systems Engineering Training & Development
- JHU APL
- Early Career Advanced Systems Project (ECASP)
- ECASP Process
- ECASP Evaluation
- Lessons Learned

Need for SE Training & Development

- **One of the NDIA top five issues:**
  "The quantity & quality of SE expertise is insufficient to meet the demands of the government & defense industry."

- **As systems increase in complexity, SE needed to plan, develop, manage, and evolve systems**

- **Strengthen expertise in new staff to maintain APL strength in SE**

Johns Hopkins University Applied Physics Laboratory

- **Not-for-profit center for engineering, research, and development**
  - **~4500 employees**
  - **8 departments spanning aerospace to biomedical**
- **Enhance national security through science and technology**
- **JHU Engineering Professionals & Systems Institute**

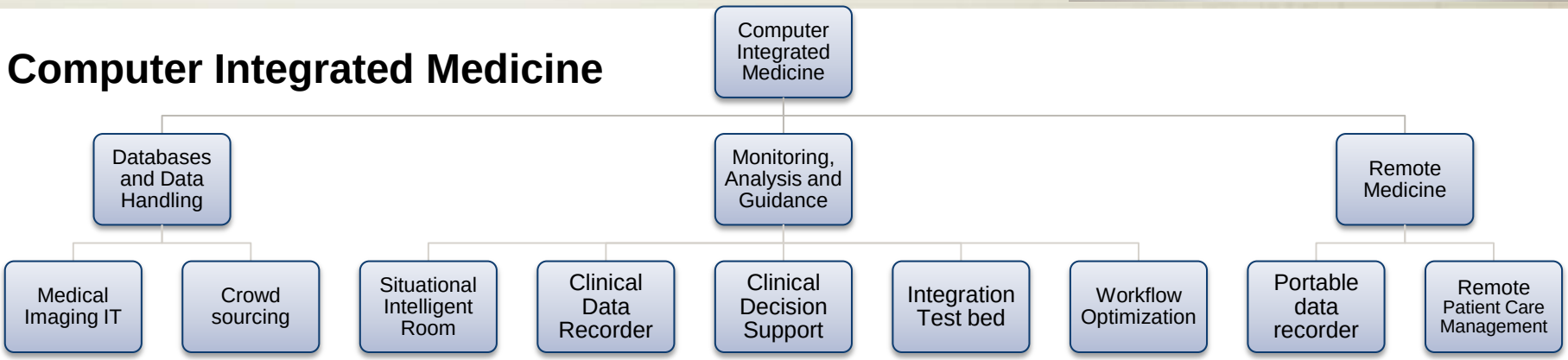
JHU Engineering Professionals

- **Part-time graduate engineering school**
  - **Weekday evenings and Saturdays in greater Baltimore-Washington area**
- **MS and eventually PhD program in SE**
- **Faculty - leading engineers and applied scientists from top private corporations and APL**

Applied and Computational Mathematics	Chemical and Biomolecular Engineering	Environmental Engineering, Science, and Management	Mechanical Engineering	Systems Engineering
Applied Biomedical Engineering	Civil Engineering	Information Assurance	Materials Science and Engineering	Bioinformatics
Applied Physics	Computer Science	Information Systems Engineering	Technical Management	Electrical and Computer Engineering

JHU APL Systems Institute

Computer Integrated Medicine



- **Multidisciplinary approach to re-engineering entire systems of national importance**
- **Collaborative projects that integrate computer technology into the healthcare system**
- **APL engineers, WSE computer scientists, clinicians and technologists from the School of Medicine and the School of Public Health**

Applying systems thinking to solve grand challenges

Traditional SE Training and Development

- **Traditional degree programs (MS or PhD)**
  - **MIT's System Design and Management - interdisciplinary degree from engineering and management school**
- **Short course offerings**
  - **Focused training on selected aspects of SE**
- **Certificate programs on SE**
  - **Series of short courses**
- **Internships & rotational programs**

Related SE Training and Development

- **Professional development courses for technical work force of various organizations**
  - **NASA's APPEL (Academy of Program/Project and Engineering Leadership)**
    - **Courses and informal knowledge sharing events and publications**
  - **NASA SEED (Systems Engineer Development) Program**
    - **Courses and job rotations for mid-career engineers**
  - **JHU/APL's ASECA (APL Systems Engineering Competency Advancement)**
    - **Courses to develop the fundamentals of quality management procedures for systems development in early career staff**

Experiential Learning

"What we have to learn to do, we learn by doing." – Aristotle

- **Experiential Learning - process of developing meaning from direct experience**
  - **Concrete experience**
  - **Observation of and reflection on that experience**
  - **Formation of abstract concepts based upon the reflection**
  - **Testing the new concepts**
- **Systems engineering skills developed by experience and not solely through traditional classroom instruction**
  - **Work experience one of the key steps in developing systems thinking**

ECASP Overview

- **Early Career Advanced Systems Project (ECASP)**
  - **Early career (1 - 5 years since college)**
  - **15 participants for 6 months at 50%**
  - **Multi-disciplinary team**
    - **BS, MS, & PhD in CS, EE, ME, SE, Psych, Physics, and Aero**
    - **All laboratory departments represented**
- **Identify and explore solutions to enhance operational capabilities using disciplined SE approach**
  - **2010-Assuring naval communications in contested environments**
  - **2011-Enhancing air support via larger Unmanned Aerial Vehicles (UAVs) from smaller ships**

ECASP Objectives

- **Provide early career staff with opportunity to develop advanced multi-mission concepts to meet national challenges**
  - **Gain systems engineering experience**
  - **Gain insight into breadth and depth of APL capabilities**
- **Provide opportunity to collaborate across APL and with military officers and civilians from sponsor community**
- **Promote cross-department collaboration**
- **Contribute innovative new approaches**

Expected Value of ECASP

ECASP provides staff with an opportunity to:

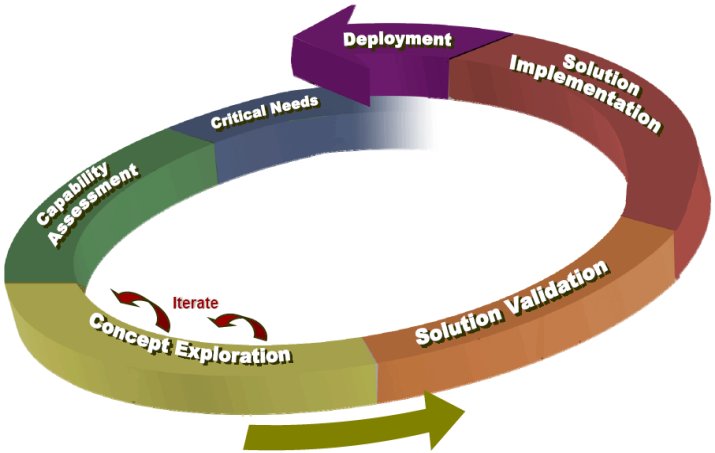
- Participate in an exciting, potentially high-impact, high-visibility project
- Collaborate with other early career professionals and senior experts from across the Lab
- Gain a broader perspective of warfighting challenges and APL's role
- Experience sponsor interactions
- Potentially establish enduring relationships with military officers
- Learn, first hand, systems engineering concept development, military protocols, and senior-level presentation skills
- Gain a better understanding of the breadth of APL tasks and expertise
- Learn how to access information and expertise from across the Lab
- Experience near-term accomplishment

Systems Engineering Topics Covered in ECASP

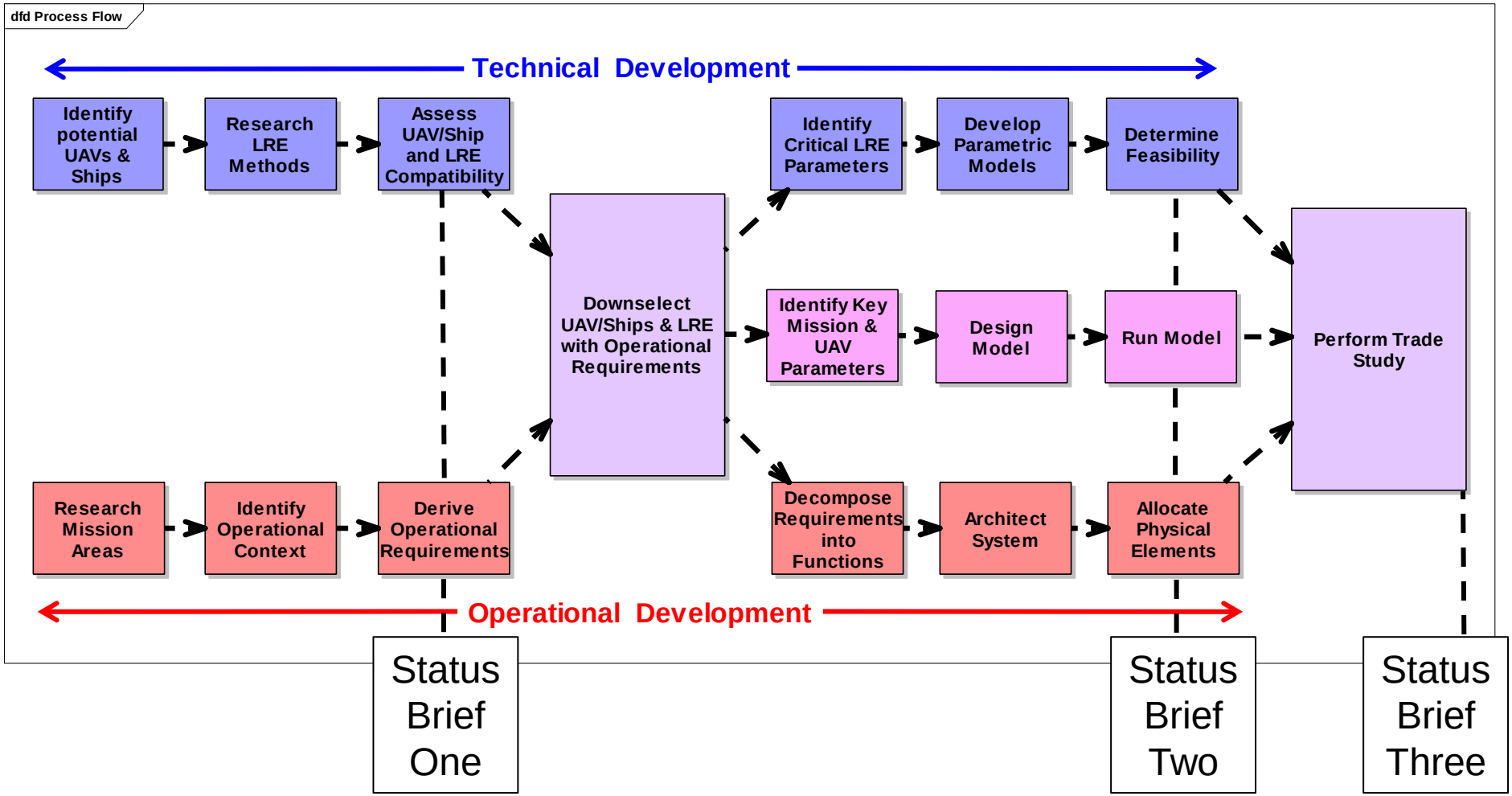
- Needs Analysis
- Mission Analysis
- Physical Allocation
- Requirements Analysis
- Technology Assessment
- Concept Validation
- Key Performance Parameters
- Trade Studies

ECASP 2011 Process Flow (1 of 2)

- Critical Needs
  - Objectives/ Scope / Guidelines
  - Operational Scenarios
  - Requirements
- Capability Assessment
  - System Definition
- Concept Exploration
  - Primary Alternative Down Selection
    - Down Selection Process
    - Operational Modeling Analysis
  - Alternative Evaluation
    - Primary Alternative Evaluation
    - Secondary Alternative Evaluation
  - Trade Study



ECASP 2011 Process Flow (2 of 2)

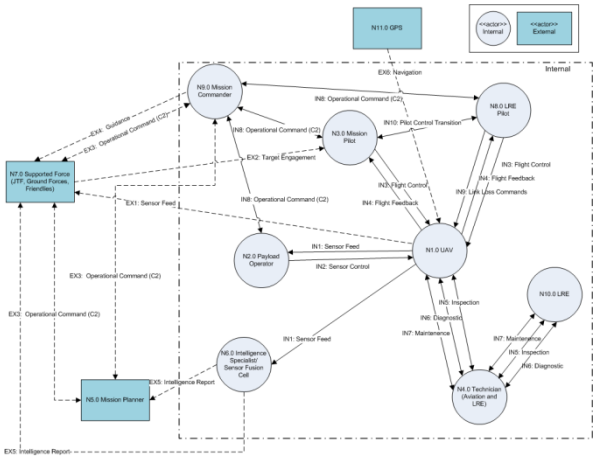


*ECASP 2011 Brief

System Definition Methodology

Operational Requirements → System Boundary → System Architecture → Physical Allocation

Information Exchange

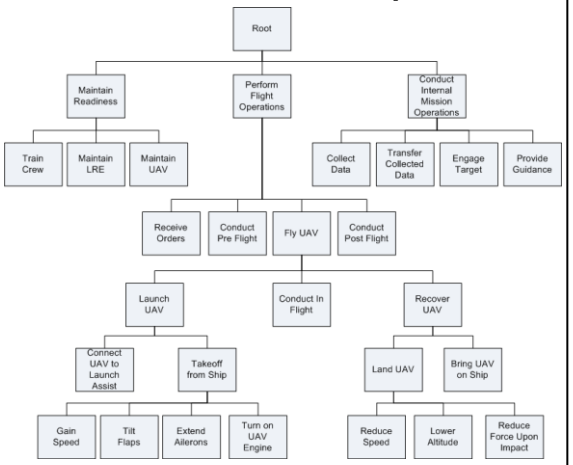


Simultaneous Operations

Simultaneous Operations

	Radio 1		Radio 2	
	SATCOM (WB)		SATCOM (NB)	
N1. UAV	N2. Payload Operator	Sensor Feed (P)	N3. Internal Pilot	Flight Feedback (P)
	N6. Intel Specialist	Sensor Feed (P)	N8. External Pilot	Flight Feedback (S)
	N7. Supported Forces	Sensor Feed (P)		
N2. Payload Operator			N1. UAV	Sensor Control (P)
N3. Internal Pilot			N1. UAV	Flight Control (P)
			N8. External Pilot	Pilot Control Transition
N4. Flight Ops Technician (LRE and UAV)				
N6. Intelligence Specialist / Sensor Fusion Cell	N5. Mission Planner	Intelligence Report		
	N7. Supported Forces	Intelligence Report		
N9. Mission Commander			N3. Internal Pilot	Operational Command
			N2. Payload Operator	Operational Command
			N7. Supported Forces	Operational Command
			N5. Mission Planner	Operational Command

Functional Decomposition



*ECASP 2011 Brief

Survey Methodology for Evaluation

- **Cross-sectional survey**
  - **Single point in time for past and present ECASP participants**
  - **Self reported evaluations**

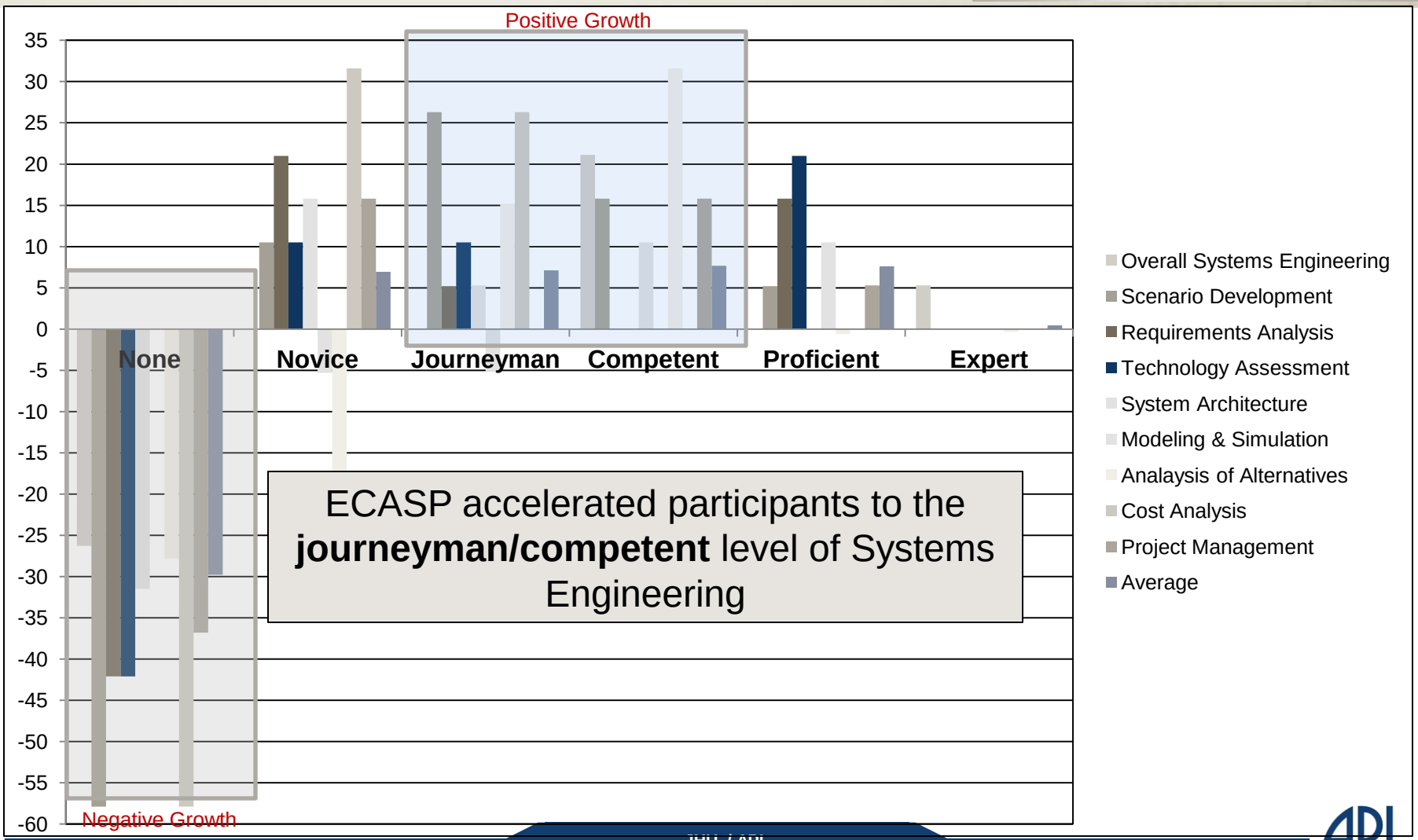
- **Representative Sampling**
  - **100% of ECASP 2011**
  - **38% of ECASP 2010**

- **Question Design**
  - **Multiple choice on level of expertise**
  - **Likert scale (Strongly disagree to Strongly agree)**
  - **Open-ended**

Level of Expertise

Level	Stage	Characteristics	How knowledge is treated	Recognition of Relevance	How context is assessed	Decision-making
0	**None**	* No knowledge of subject	N/A	N/A	N/A	N/A
1	**Novice**	* Minimal textbook knowledge without practice * Rigid adherence to rules * Little situational perception	Without reference to context	None	Analytically	Rational
2	**Advanced Beginner/ Journey-man**	* Working knowledge of key aspects of practice * Situational perception limited * All attributes and aspects are treated separately and given equal importance	In context			
3	**Competent**	* Good working and background knowledge of areas of practice * Copes with complex situation through deliberate analysis and planning * Standardized and routine procedures * Views actions in terms of longer-term goals		Present		
4	**Proficient**	* Depth of understanding in discipline & area of practice * Perceives deviations from the normal pattern * Deals with complex situations more holistically			Holistically	
5	**Expert**	* No longer relies on rules, guidelines or maxims * Excellence achieved with relative ease * Vision of what is possible * Authoritative knowledge of discipline & deep tacit knowledge across area of practice * Analytic approaches used only in novel situations or when problems occur				Intuitive

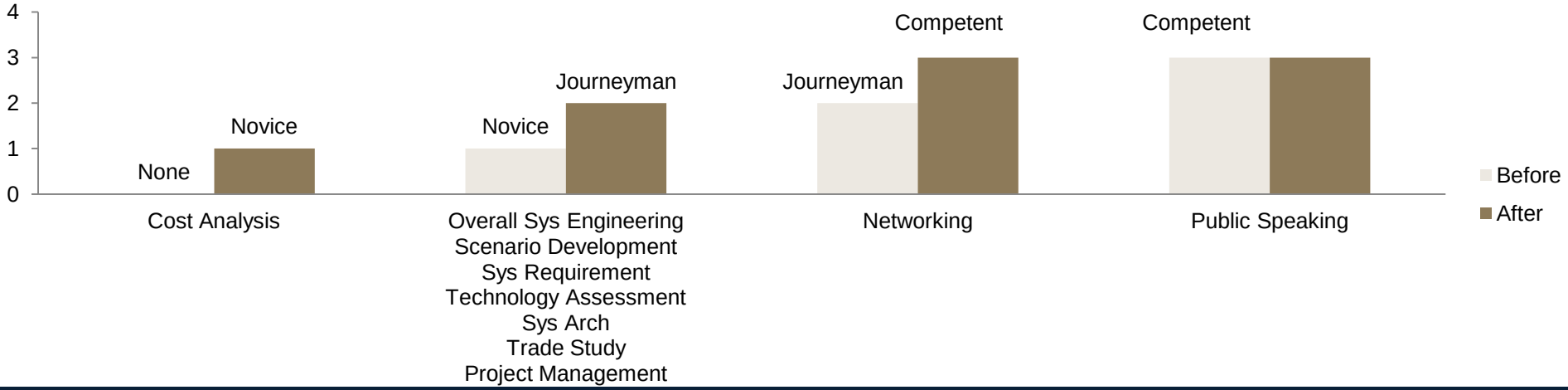
Systems Engineering Growth (1 of 3)



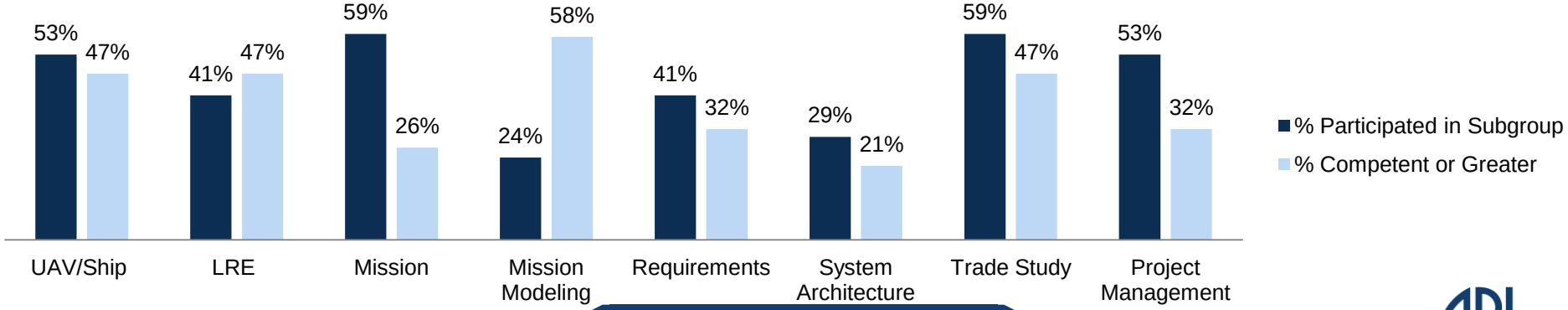
ECASP accelerated participants to the **journeyman/competent** level of Systems Engineering

Systems Engineering Growth (2 of 3)

Average Level of Expertise Before and After ECASP



Subgroups in ECASP



Systems Engineering Growth (3 of 3)

- **Overall most participants felt that they moved from the None/Novice level to the Journeyman/ Competent level**

- **Biggest Growth Areas:**
  - **Trade Study**
  - **Technology Assessment**
  - **Overall Systems Engineering**

Survey Results (1 of 2)

Advantages

- Exposure to military perspectives
- Experience re-evaluating trade space when no perfect solution exists
- Expanded professional networks
- Project management skills
- Teambuilding
- Leadership experience

Disadvantages

- Uneven depth of expertise development depending on subgroups
- Struggling between a technology-driven versus a mission/requirements-driven project
- Difficulty scoping the problem

Survey Results (2 of 2)

- 79% broadened their appreciation for sponsor needs and challenges
- 84% learned a new tool while in ECASP
- 79% of participants used knowledge gained in ECASP immediately on other projects

Lessons Learned (1 of 2)

- **Organization is key to successful projects. Identifying Team Leads early allows a few team members to focus on project management tasks & focus technical work**
- **Develop technical process plans and risk mitigation strategies early in the project in case solutions are not feasible**
- **"Technology Push" and "Operational Pull" perspectives do not always coincide. Scoping the problem is necessary to balance these two items**
- **Network, Network, Network: Identify & Engage contacts and SMEs as early as possible. The right expert at the right time saves time and effort**
- **Collaboration is a requirement for a large team. Sharepoint, Wikis, and team co-location were critical to the project success. Mentors & participants should develop a regular meeting pattern**

*ECASP 2011 Brief

Lessons Learned (2 of 2)

- Department level software licensing makes cross-departmental collaboration difficult. The team had to rely on software readily available to all departments even if that software was not the best tool for the job
- Engineering judgment and parametric modeling approaches are essential when actual data is not available
- Utilize SE methods and processes to reduce the level of subjectivity that is inherent to the trade-study process. Conduct sensitivity analyses to ensure that small variations in subjective results do not impact trade-study results to a large degree
- Cost estimates for the entire acquisition / system life-cycle are difficult to determine. Cost does not always play well with other trade-study parameters
- Perfect solutions do not exist; re-evaluation of trade space may be necessary

*ECASP 2011 Brief

Conclusions

- **Generalizable to other organizations**

- **Educational Framework**
  - **Develop system engineering expertise**
  - **Encourage technical innovation**
  - **Foster sponsor engagement**

- **Framework applicable to any skill central to an organization where experience is vital**

ECASP Organizers & Mentors

- John Benedict
- Mike Shehan
- Mike “Moose” Moreno
- Chris Evans
- Jerry Krill
- Aili Kujawa

Questions??

The Johns Hopkins University
APPLIED PHYSICS LABORATORY

Backup Slides

The Johns Hopkins University
APPLIED PHYSICS LABORATORY

ECASP 2011 Challenge

- **Perceived Operationally Useful Capability**
  The U.S. Navy does not have the capability to launch and recover long endurance Unmanned Aerial Vehicles (UAVs) from small ships

- **Operational Context**
  Provide improved technology solutions for Air Support to Maritime Security and Ground Operations

- **ECASP Goal**
  Apply a systems engineering approach to identify possible solutions

*ECASP 2011 Brief