SYSTEMS ENGINEERING
Research Center

Early Findings from Interviewing Systems Engineers Who Support the U.S. Department of Defense

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Outline

- Motivation
- Overview of the Helix Project
- Early Findings
  - — The most important characteristics and competencies of effective systems engineers
  - — The career paths of senior systems engineers (updated fr. Report II)
  - — The greatest self-reported contributions of systems engineers
  - — The factors that have the greatest positive impact on systems engineers' effectiveness (include updates on Experience)
  - — The factors that have the greatest negative impact on systems engineers' effectiveness
- A Sneak Peek: Findings Since Paper Submittal
  - — Career Path Analysis: Motivation and Methodology
  - — Taxonomy: Seniority of Systems Engineers
- Future Direction for Helix: Building a Theory of Systems Engineers

Motivation

- Systems Engineering is a critical factor in the successful development of increasingly complex and interconnected systems
- US DoD is eager to understand
  - The capabilities of its existing SE workforce
  - The capabilities of the existing defense industry workforce
  - Any capability gaps that will impact the development of future systems
  - How retirement of senior systems engineers will impact overall workforce capabilities

Helix Study

- Helix is a multi-year longitudinal study designed to build an understanding of the systems engineering workforce in the DoD and the Defense Industrial Base (DIB) *(that scope is expanding)*
- Data collection has primarily been through semi-structured interviews with systems engineers
- Reporting is done in an aggregated anonymous manner that does not reveal the identities of participating individuals or organizations

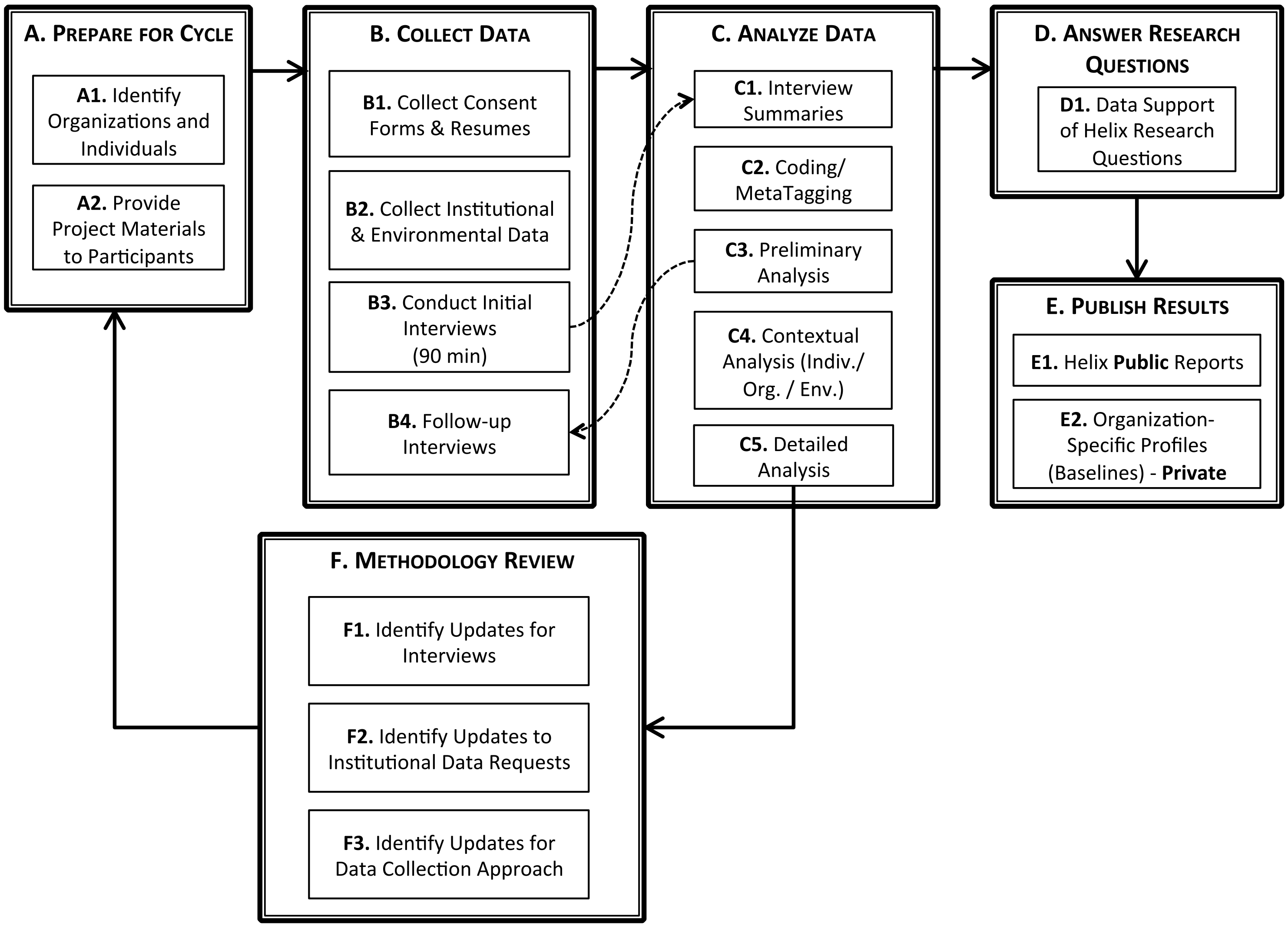
Helix Research Questions

- Helix is focusing on three main research questions:
  1. What are the characteristics of systems engineers?
  2. How effective are systems engineers and why?
  3. What are employers doing to improve the effectiveness of their systems engineers?

Helix Methodology

- Phases 1 and 2:
  - Grounded theory approach
  - Loosely structured conversations with systems engineers
  - Data mining to identify patterns or areas of interest
- Phases 3 and 4:
  - Using data, develop a framework of systems engineers
  - Update interview protocols to collect new data to help refine and validate this framework
  - Conduct a focused workshop to get detailed feedback on the validity and applicability of the framework

Helix Process



Organizational Questions

- The charter or primary purpose of your organization
- The primary business of your organization, including revenue, primary customer, organization chart, and types of products and services delivered
- Total number of employees in the organization in each year since 2009, divided into engineers and non---engineers, including the number of people hired and departed
- Total number of systems engineers in the organization in each year since 2009 including the number of people hired and departed, however the organization defines "systems engineer"
- A characterization of your systems engineer population with respect to highest college degree, number of years of professional experience, number of years of experience as a systems engineer, age, gender, title or rank (such as systems engineer, senior systems engineer, chief systems engineer, etc. using whatever titles or ranks that are part of your human resources system), and years to retirement eligibility
- The way in which your systems engineers are primarily organized; e.g., in a matrix structure or project structure (n.b. pre- and post- recent organization change would be preferred)
- Major organizational initiatives now underway to improve the quality or quantity of systems engineers Policies that are particularly relevant to systems engineers, including organizational competency model, definition of systems engineer, and career paths

Helix Data Collection to Date

- **8** DoD and DIB organizations participated in Helix interviews
- **135** systems engineers interviewed
  - 65 follow up interviews to date
- Over **2000** pages of raw data
- Qualitative and quantitative research methods applied, based on grounded-theory approach
- Early findings reported in December 2013 (INCOSE paper) and April 2014

Early Findings

- The most important characteristics and competencies of effective systems engineers
- The career paths of senior systems engineers
- The greatest self-reported contributions of systems engineers
- The factors that have the greatest positive impact on systems engineers' effectiveness
- The factors that have the greatest negative impact on systems engineers' effectiveness

Characteristics

- *Paradoxical mindset*
  - Both big picture thinking and attention to detail;
  - Both strategic and tactical;
  - Both analytic and synthetic;
  - Both courageous and humble; and
  - Both methodical and creative.
- *Effective communications*:
  - Modes of Communication
  - Audience
  - Content
  - Purpose
- *Flexible comfort zone*
- *Smart Leadership*
- *Self-Starter*

Technical Competency

- **You do not have to be the strongest specialty engineer to be an effective systems engineer**
  - Understand the information provided by deep technical experts;
  - Know who to reach out to when technical questions out of one's depth arise;
  - Understand when technical information provided seems 'off' and follow up with the right questions; and
  - Have credibility with his or her team.

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Contributions of Systems Engineers

- First Cut
  - Translating highly technical information from Subject Matter Experts (SMEs) into common language that other stakeholders can understand;
  - Providing a balance of project management concerns (cost/schedule) with technical requirements;
  - Asking the right questions;
  - Seeing relationships between the disciplines;
  - Staying "above the noise" and identifying pitfalls;
  - Managing emergence in both the project and the system;
  - Projecting into the future; and
  - Getting the "true" requirements from the customer.

- Refined view – each of these things fits into:
  - Correctly identifying the needs of the customer
  - Providing clarity on the system vision
  - Communicating the system vision
  - Delivering on the needs of the customer

Factors That Positively Influence Effectiveness

- Diverse Experiences:
  - Different parts of the SE life cycle;
  - Different types of life cycles, e.g.
    - Quick Reaction Capability (QRC);
    - More formal acquisition life cycles, aligning with DoD 5000.2;
    - Internal research and development (IR&D) projects;
  - Different aspects of a system (part, component, subsystem, system).

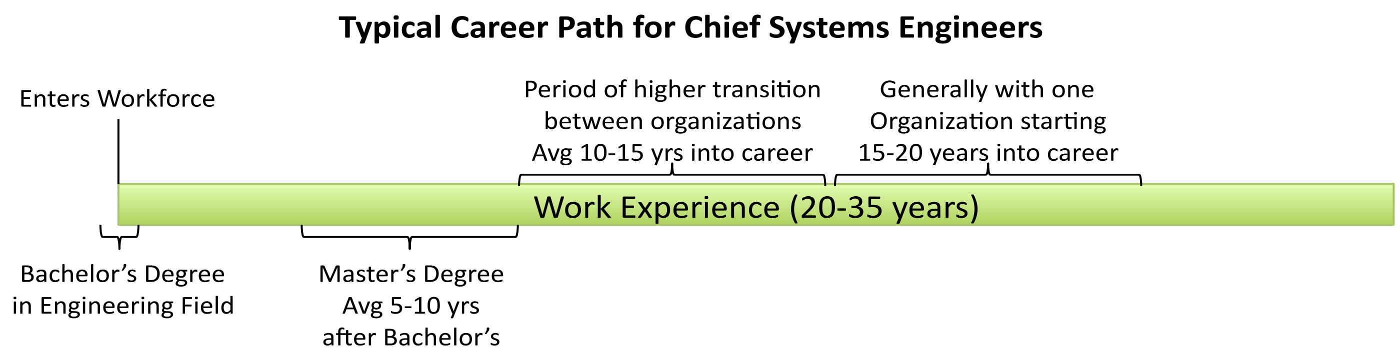
- Mentoring: a strong accelerating function for growing the competencies and a tool that enables systems engineers to get more value from their experiences
  - Career mentorship
  - Organizational mentorship
  - Technical mentorship

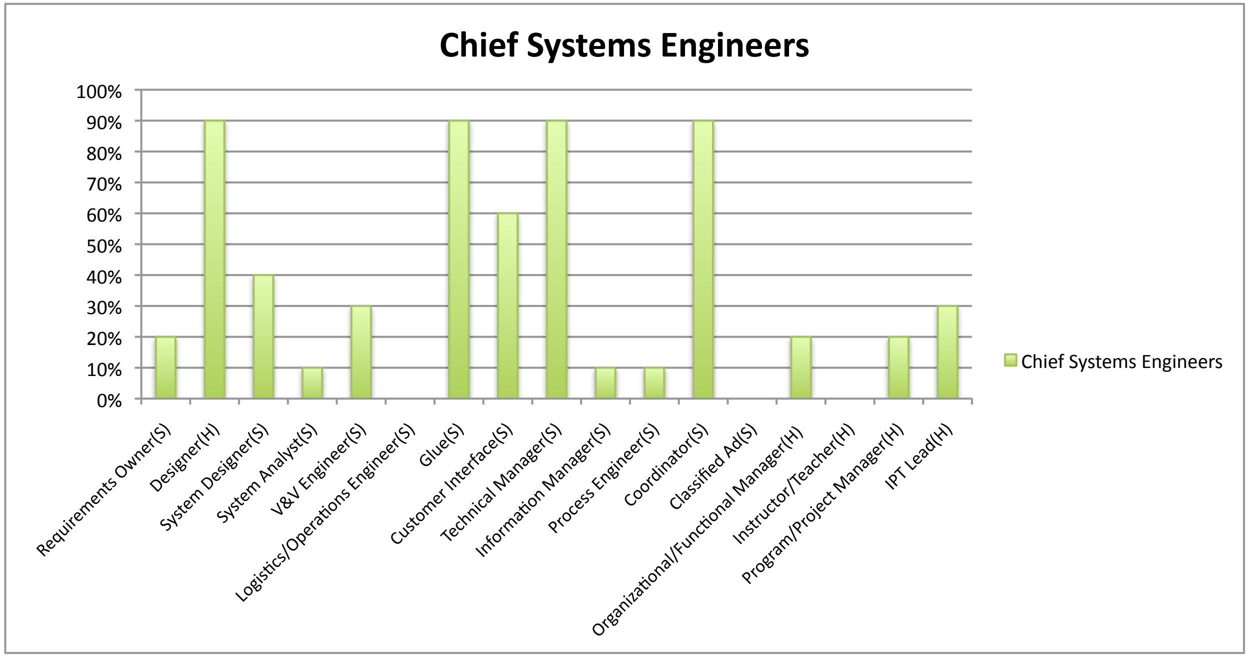
	Organization-Acknowledged	Organization-Neutral
Formal	✓	✗
Informal	✓	✓

Factors That Negatively Influence Effectiveness

- Definition of systems engineering (or lack thereof)
- Definition of a systems engineer
- How SE is valued in the culture
  - Valuing process over critical thinking
  - Failures are more visible than successes
  - Push-back on up front costs
- Lack of tools to support SE work

Career Paths for Senior SEs: Chief Systems Engineers





Career Path Analysis: Motivation and Methodology

- Motivation
  - It is widely agreed that experience is critical to the development of systems engineers BUT – what types of experiences, how much experience, etc. is debated
  - Understanding the professional experiences – the career paths – of systems engineers is a critical first step in understanding the role of experiences in workforce development
- Methodology – the general approach includes:
  - Review of resumes submitted by each individual;
  - Review of first interview transcripts and notes; and
  - Review of preliminary results during follow up interviews to clarify analysis.

Career Path Analysis: Early Results

- Examination of
  - The different life cycle stages experienced by each individual;
  - The variety of programs worked on by each individual, including program size and type;
  - The variety of programs worked on by each individual, including program type and application domain;
  - The number and type of organizations worked in by each individual; and
  - The role(s) played by each individual.
- Identification of individuals based on seniority (junior, mid-level, or senior);

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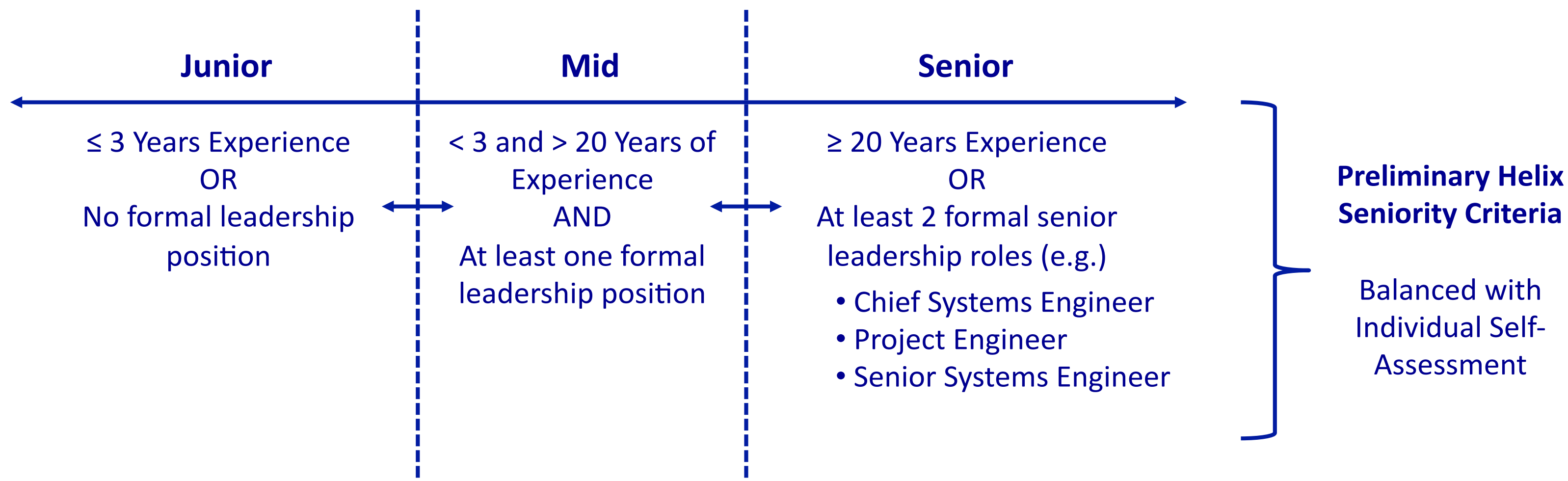
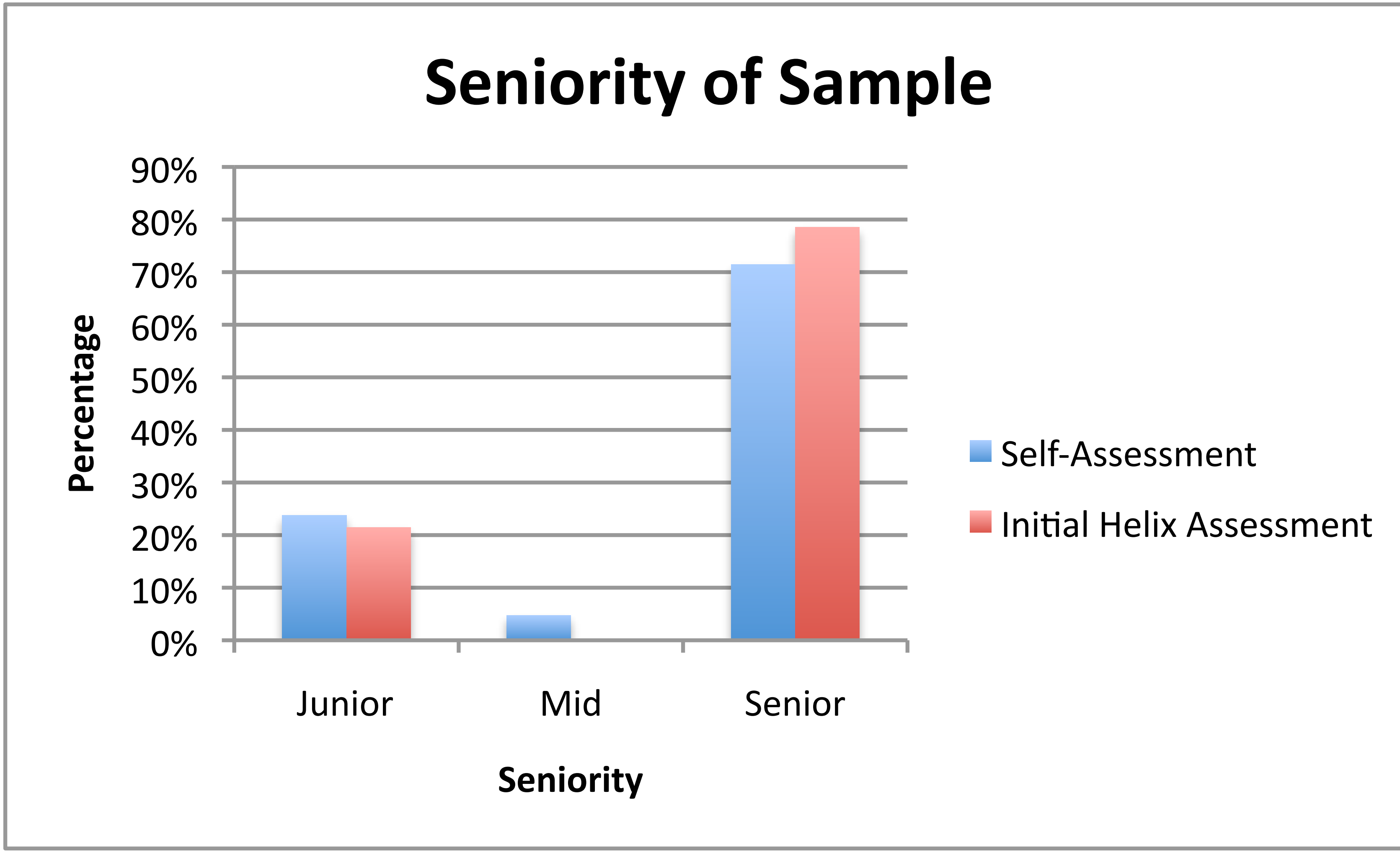
Taxonomy: Seniority of Systems Engineers

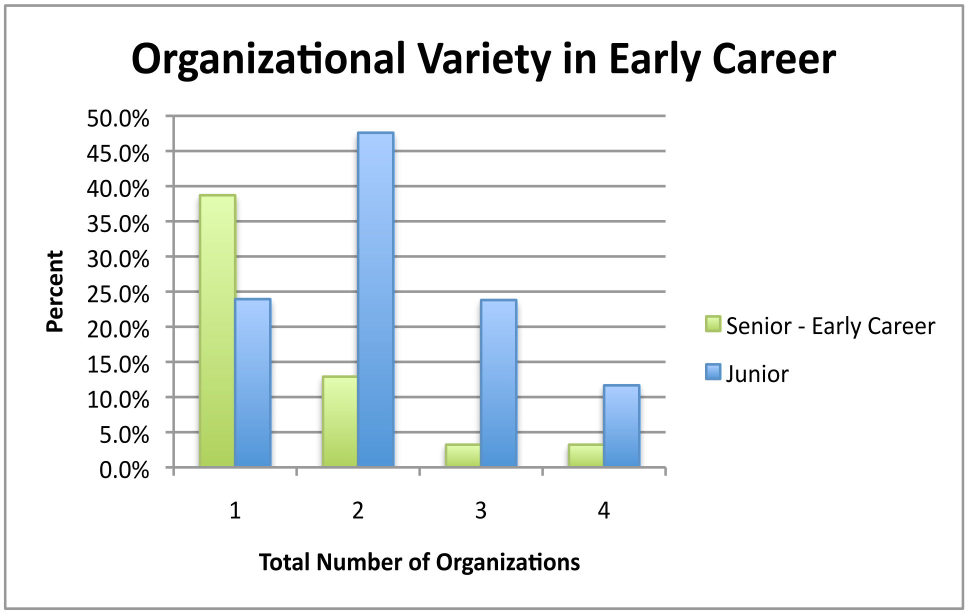
- No consistent seniority criteria across organizations
- Delineating people who are early versus late in their careers helps to distinguish between groups with different capabilities that fill different roles



Seniority of Systems Engineers: Helix Data



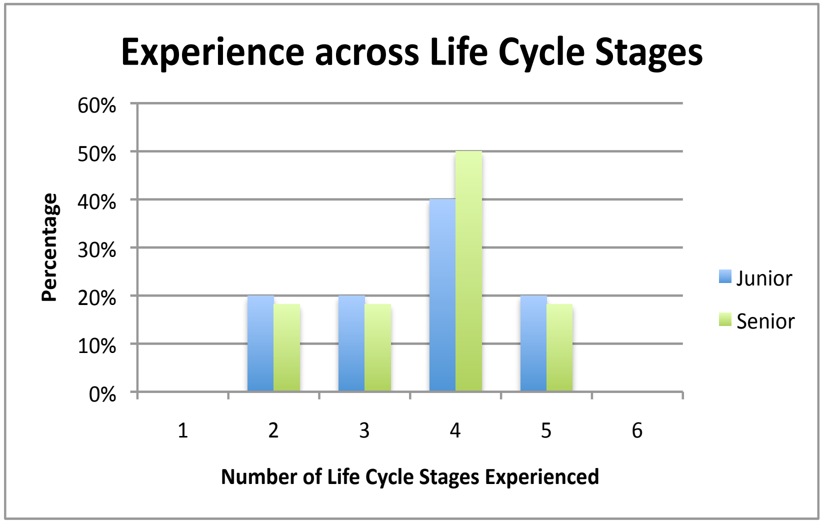
Diversity of Experiences: Organization Diversity in Early Career



- Reasons for more mobility in early career today
  - Positional Impatience
  - Positional Stagnation
  - Work-Life Balance

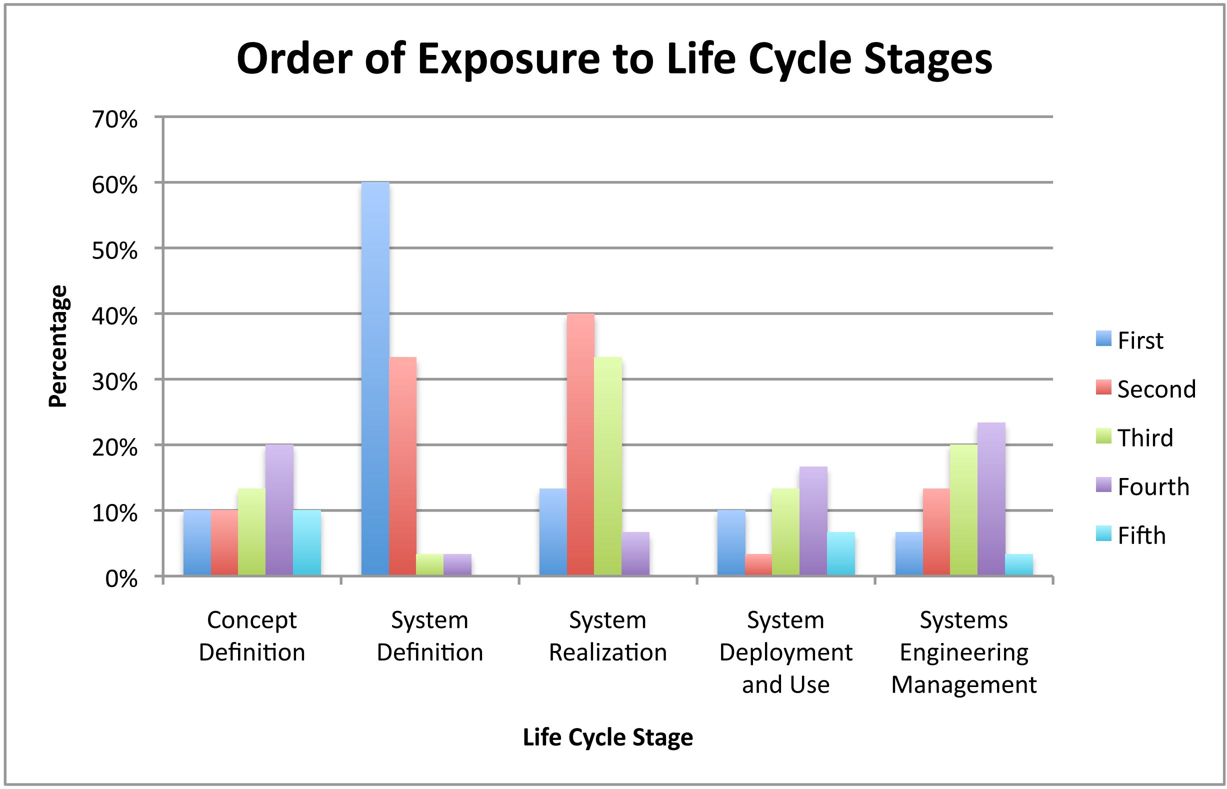
Diversity of Experiences: Across the Systems Engineering Life Cycle

- Terminology for SE Life Cycle is not always consistent.
- Helix team translated into common framework from the SEBoK
  - **Concept Definition**
  - **System Definition**
  - **System Realization**
  - **System Deployment and Use**
  - **Product and Service Life Management**
  - **Systems Engineering Management** – managing the resources and assets allocated to perform systems engineering activities.

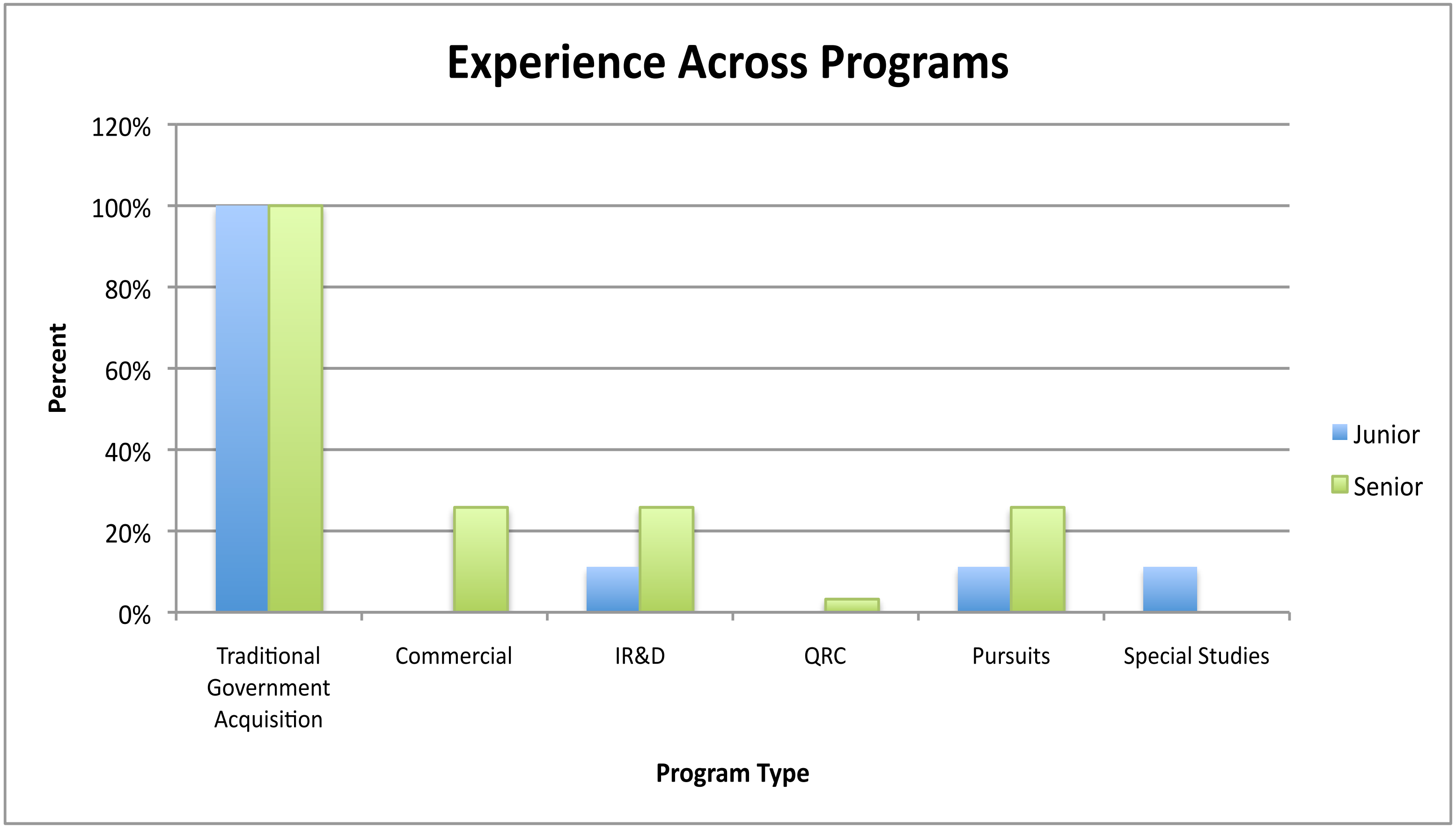


Diversity of Experiences: Across the Systems Engineering Life Cycle

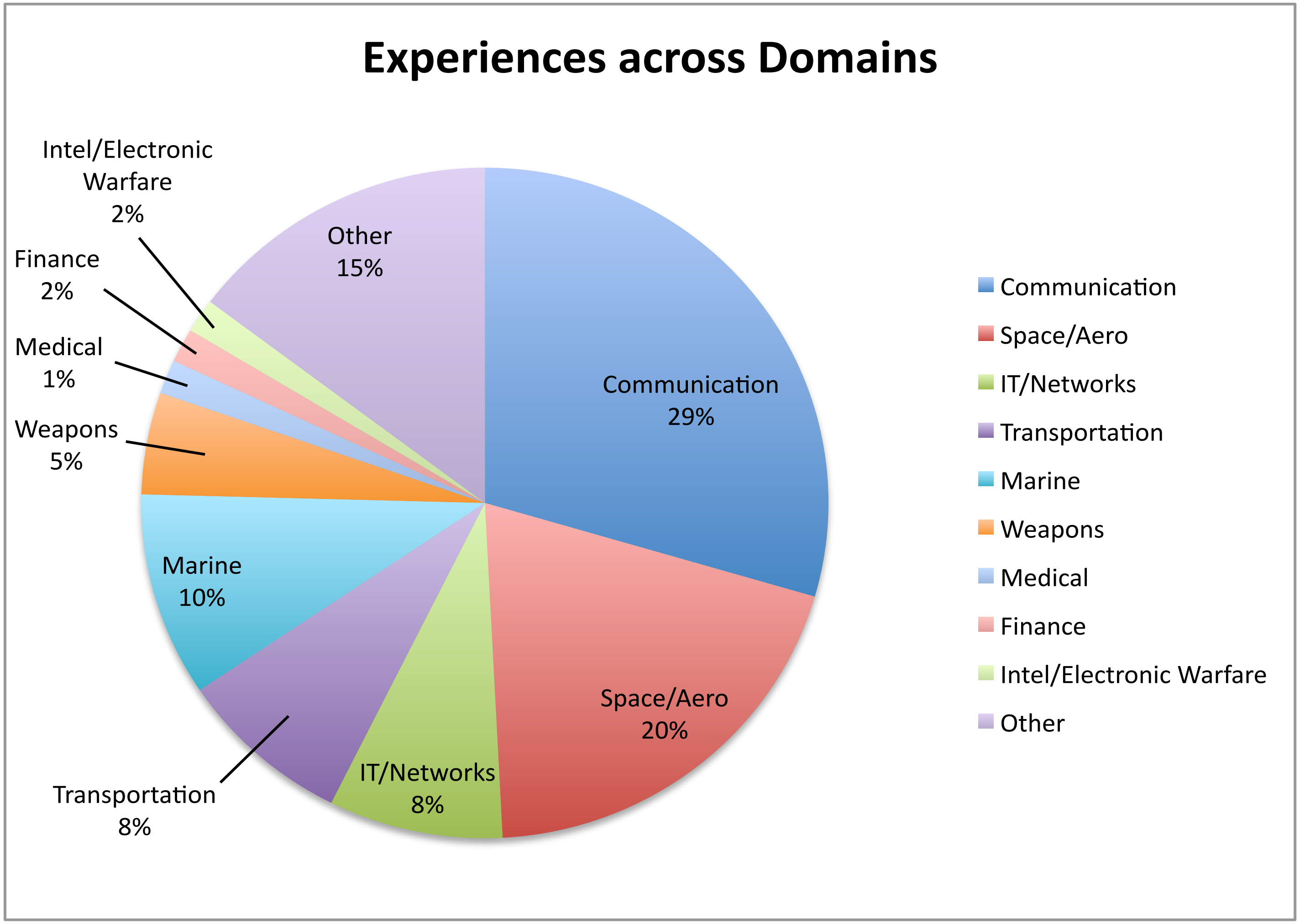
- Over 90% of the current sample is exposed to System Definition as either the first or second life cycle stage they experience.
- Over 70% of the sample experience System Realization as either the second or third stage of the life cycle to which they are exposed.



Diversity of Experience: Program Types



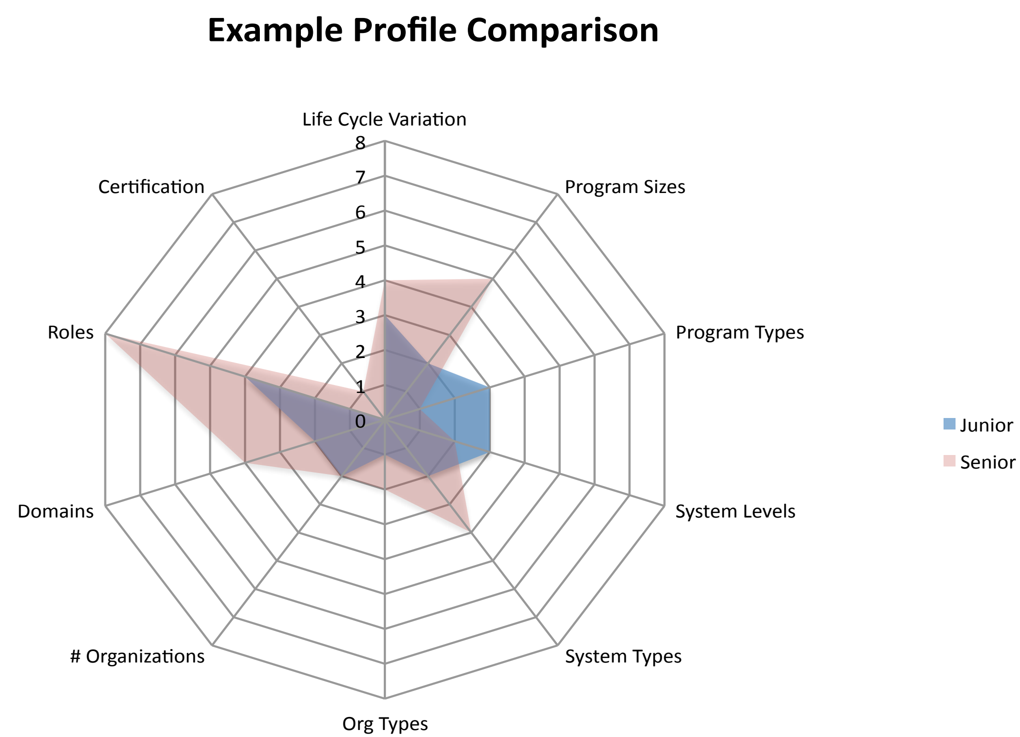
Diversity of Experiences: Application Domains



Diversity of Experiences: Roles

Future Directions for Career Analysis

- Additional Data Collection and Analysis
  - —Program sizes (dollar value, number of individuals on team, etc.);
  - —System type (product, platform, service, enterprise); and
  - —System level (component, subsystem, system, system of systems).



- Build Comparable Career Profiles

Future for Helix: Building a Theory of Systems Engineers

- Theory will explain the contributing factors for effectiveness of a systems engineer in a particular role, as a function of several variables and their inter-relationships. The three proposed aggregate variables at this time, with respect to a systems engineer, are:
  - Personal experiences
  - Personal characteristics
  - Environment

Thank you!

- Questions?

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Backup

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Diversity of Experiences: Roles

Sheard/ Helix	Role	Description
Sheard	**Requirements Owner**	Individual responsible for translating customer requirements to system or sub-system requirements or developing the *functional* architecture.
Sheard	**System Designer**	Individual responsible for owning or architecting the system; common titles may includes chief systems engineer, system architect.
Helix	**Designer**	Individual who provides technical designs that match the system architecture; an individual contributor in any engineering discipline who provides part of the design for the overall system. This is not a systems engineering role, per se, so is not included in Sheard's roles (1996). However, as many systems engineers start in specialty design, it is reasonable to assume that this is still an important role in the early maturation of a systems engineer.
Sheard	**System Analyst**	Individual who provides modeling or analysis support to system development activities and helps to ensure that the system as designed should meet specification.
Sheard	**V&V Engineer**	Individual who plans and conducts verification and validation activities, such as testing, demonstration, simulation, etc.

Diversity of Experiences: Roles

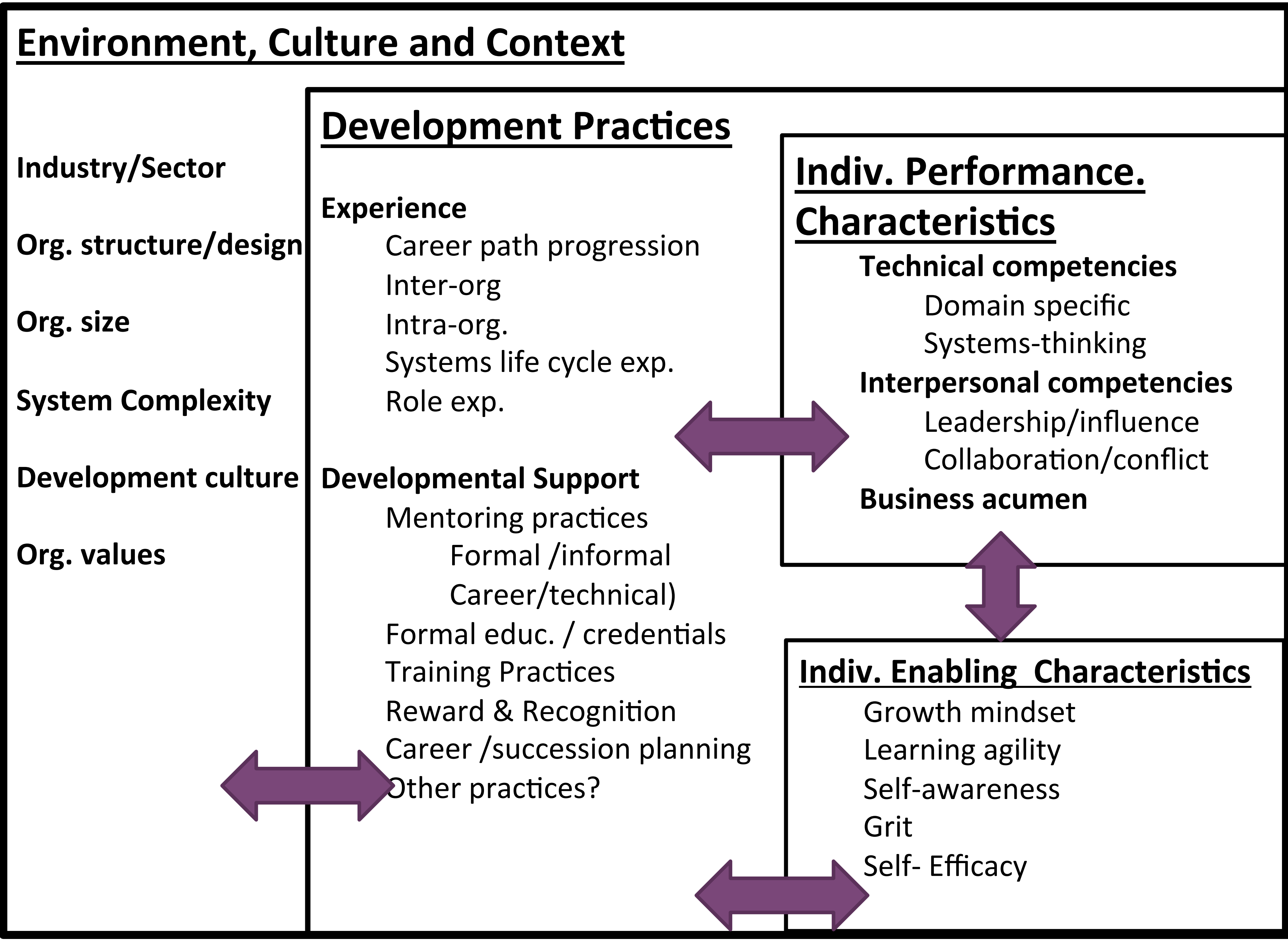
Sheard/ Helix	Role	Description
Sheard	**Logistics/ Operations Engineer**	Sheard identifies this as an individual who performs the 'back end' of the systems engineering life cycle, who may operate the system, provide support during operation, provide guidance on maintenance, or help with disposal.
Sheard	**Glue**	Individual who is responsible for a holistic perspective on the system; from Sheard (1996), this may be the "technical conscience" or "seeker of issues that fall 'in the cracks'", particularly someone who is concerned with interfaces.
Sheard	**Customer Interface**	Individual who is responsible for coordinating with the customer, particularly for ensuring that the customer understands technical detail and that a customer's desires are, in turn, communicated to the technical team.
Sheard	**Technical Manager**	Individual who is responsible for controlling cost, schedule, and resources for the technical aspects of a system; often someone who works in coordination with an overall project or program manager.
Sheard	**Logistics/ Operations Engineer**	Sheard identifies this as an individual who performs the 'back end' of the systems engineering life cycle, who may operate the system, provide support during operation, provide guidance on maintenance, or help with disposal.

Diversity of Experiences: Roles

Sheard/ Helix	Role	Description
Sheard	**Information Manager**	Individual responsible for the flow of information in a system development activity; specific activities may include configuration management, data management, or metrics.
Sheard	**Process Engineer**	Individual responsible for the systems engineering process as a whole, who likely has ties into the business directly.
Sheard	**Coordinator**	Individual responsible for coordinating amongst a broad set of individuals or groups who help to resolve systems issues; key associated skills would include negotiation, mediation, and communication.
Helix	**Organizational/ Functional Manager**	Individual responsible for the personnel management of systems engineers or other technical personnel in a business – not a project or program – setting. While this is not a "systems engineering" role, it does provide opportunities for individuals to build non-technical skills such as leadership and communication and is, therefore, included in the analysis for systems engineers.
Helix	**Instructor/ Teacher**	An individual responsible for providing or overseeing instruction of systems engineering discipline, practices, processes, etc. While not a "systems engineering' role, per se, an individual who provides training or education must have some level of mastery of the subject matter and has multiple opportunities to improve skills such as communication.

Diversity of Experiences: Roles

Sheard/ Helix	Role	Description
Helix	**Program/Project Manager**	An individual who performs program or project management activities. As defined by PMI, project management is the application of knowledge, skills, tools, and techniques to project activities to meet the project requirements. (PMI 2012) Program management is the application of knowledge, skills, tools, and techniques to a program to meet the program requirements and to obtain benefits and control not available by managing project individually. (PMI 2012) A program or project manager is not directly responsible for the technical content of a program, but works closely with technical experts and other systems engineers. Therefore, this is considered a relevant role for this analysis.
Helix	**IPT Lead**	An individual who has been assigned and executes authority for an integrated product team (IPT). Sheard includes IPT lead under the heading of "Coordinator". However, the role of IPT Lead seems to involve a broad variety of skills beyond coordination and, as a formal leadership role, seems useful to call out separately for this analysis.
Sheard	**Classified Ad**	Sheard includes a category for the types of roles often posted in job listings for systems engineers; often these are things like "Microsoft Systems Engineer". (Sheard 1996) This really equates to a computer, software, or information technology engineer.


Environment, Culture and Context
Industry/Sector
Org. structure/design
Org. size
System Complexity
Development culture
Org. values
Development Practices
Experience
Career path progression
Inter-org
Intra-org.
Systems life cycle exp.
Role exp.
Developmental Support
Mentoring practices
Formal /informal
Career/technical)
Formal educ. / credentials
Training Practices
Reward & Recognition
Career /succession planning
Other practices?
Indiv. Performance.
Characteristics
Technical competencies
Domain specific
Systems-thinking
Interpersonal competencies
Leadership/influence
Collaboration/conflict
Business acumen
Indiv. Enabling Characteristics
Growth mindset
Learning agility
Self-awareness
Grit
Self- Efficacy

Paradoxical Mindset: Systems Thinking balanced with Technical Details

Experiences to Develop Paradoxical Mindset:

- Application of a traditional engineering domain on a specific problem
- Breadth across the life cycle
- Breadth across the organization
- Performance of multiple roles

What it takes to do the detailed technical work

Issues that arise in the details

Understanding of how decisions flow through the life cycle

Understanding details of processes within SE phases

Understanding of how to get things done in the organization

Understanding of multiple stakeholders

Over time develop pattern-recognition

↓

Cognitive Changes that enable balance of perspectives

Paradoxical Mindset: Systems Thinking balanced with Technical Details

Experiences to Develop Paradoxical Mindset:

- Application of a traditional engineering domain on a specific problem
- Breadth across the life cycle
- Breadth across the organization
- Performance of multiple roles

Culture influences

What it takes to do the de

Issues that arise in the det

Understanding of how de

the life cycle

Understanding details of processes within SE phases

Understanding of how to get things done in the organization

Understanding of multiple stakeholders

Successful Mentoring Accelerates

Over time develop pattern-recognition

Cognitive Changes that enable balance of perspectives