SYSTEMS ENGINEERING
Research Center

Helix
Understanding What Makes Systems Engineers and Systems Engineering Effective

Nicole Hutchison, PI

Dinesh Verma, Co-PI

Ralph Giffin, Pam Burke, Megan Clifford, Sergio Luna - Researchers

nicole.hutchison@stevens.edu

Helix Project

- Helix is a multi-year longitudinal study building an understanding of the systems engineering workforce in the DoD, the Defense Industrial Base (DIB), and other sectors that perform systems engineering.
- From 2012-2016, Helix focused on three main research questions:
  1. What are the characteristics of systems engineers?
  2. How effective are those who perform SE activities and why?
  3. What are employers doing to improve the effectiveness of systems engineers?
- Most data collection has been through face-to-face, 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 Dataset

Participant Organizations: 22

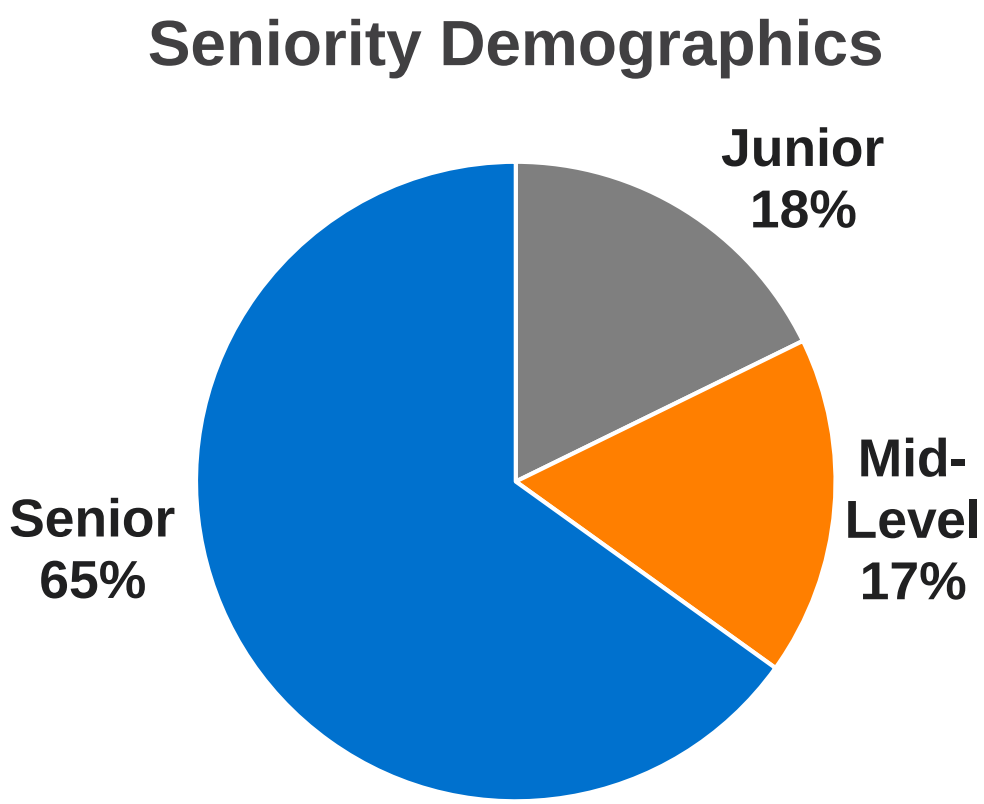
Individuals Interviewed: 335

Practicing Systems Engineers/Leadership: 92%

Systems Engineers' Peers: 8%

Pages of Transcripts: > 6000

Seniority of Systems Engineers: Helix data

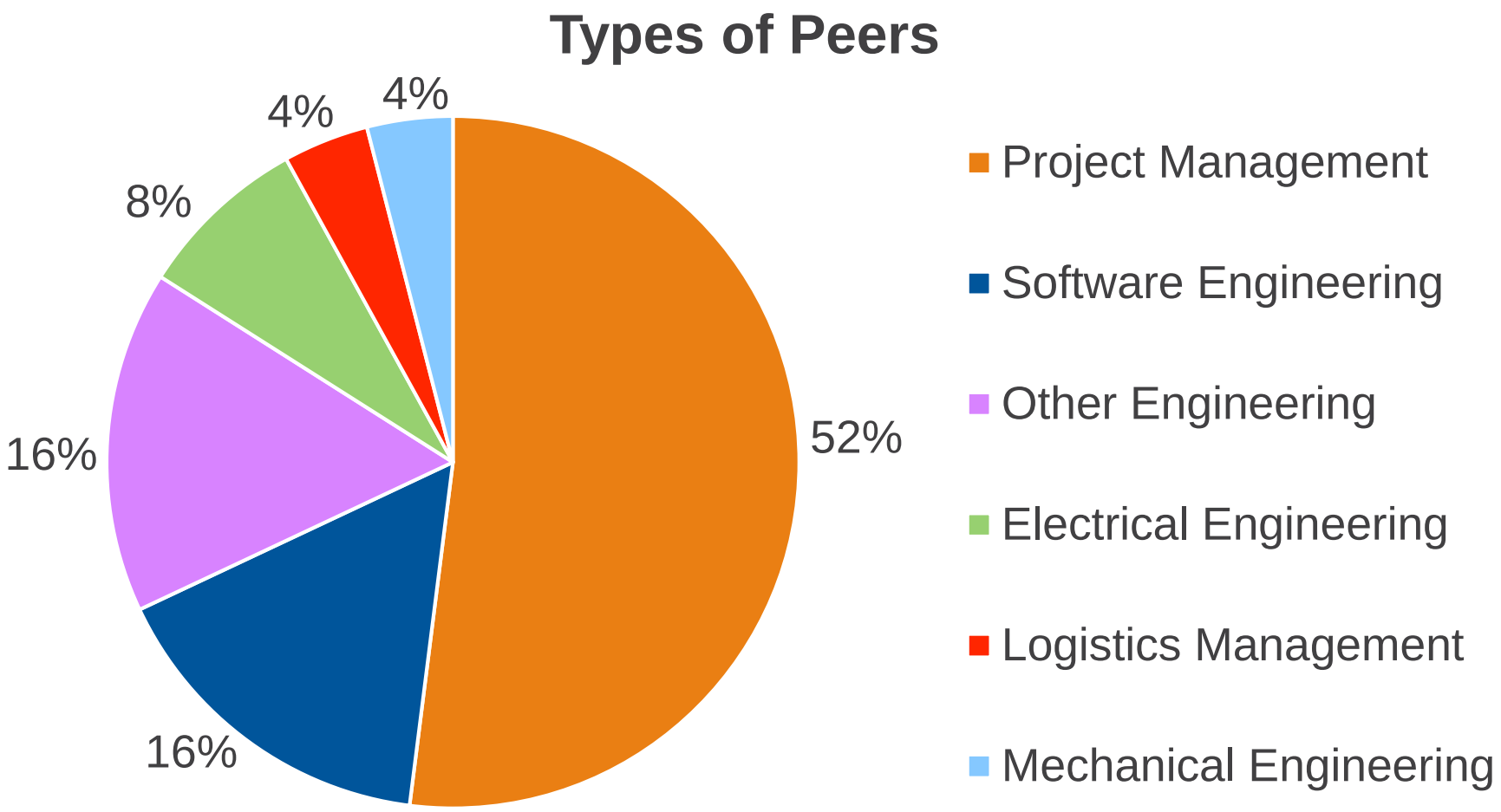


Why do we care about seniority?

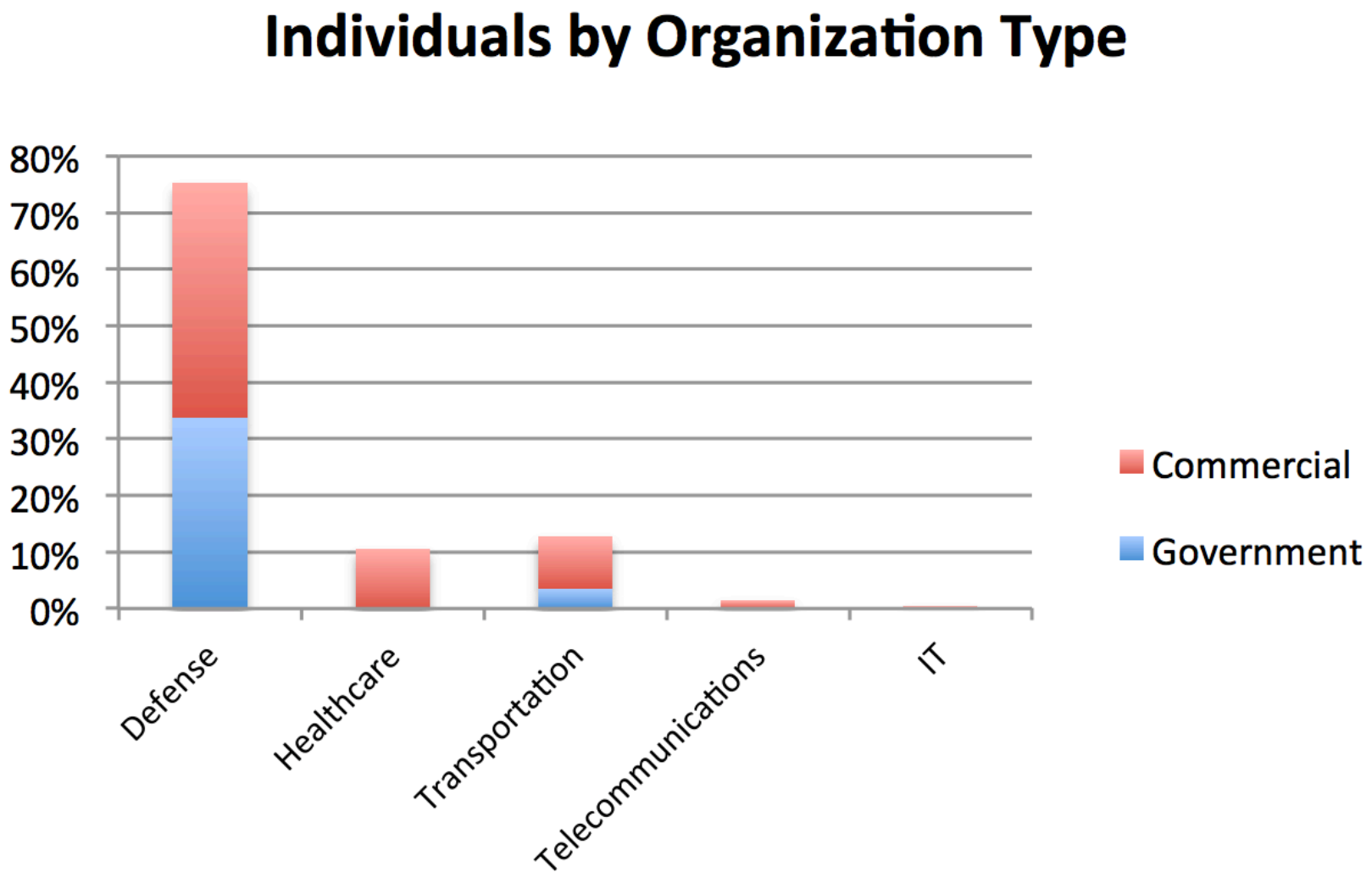
It allows us to:

- Compare across individuals and groups at different parts of their careers
- Highlight differences in the way that senior systems engineers have developed and how junior and mid-level systems engineers are developing

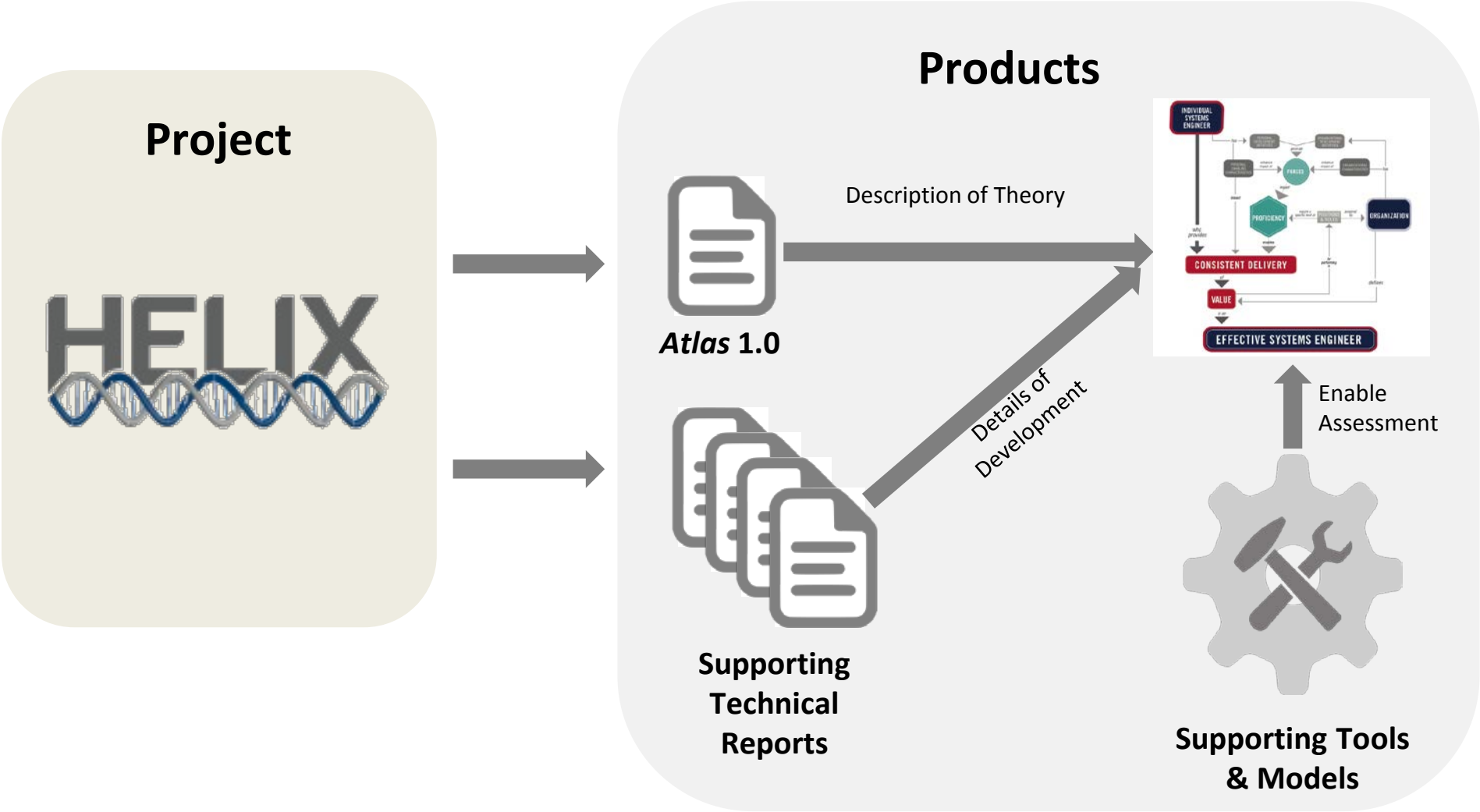
Systems Engineers Peers



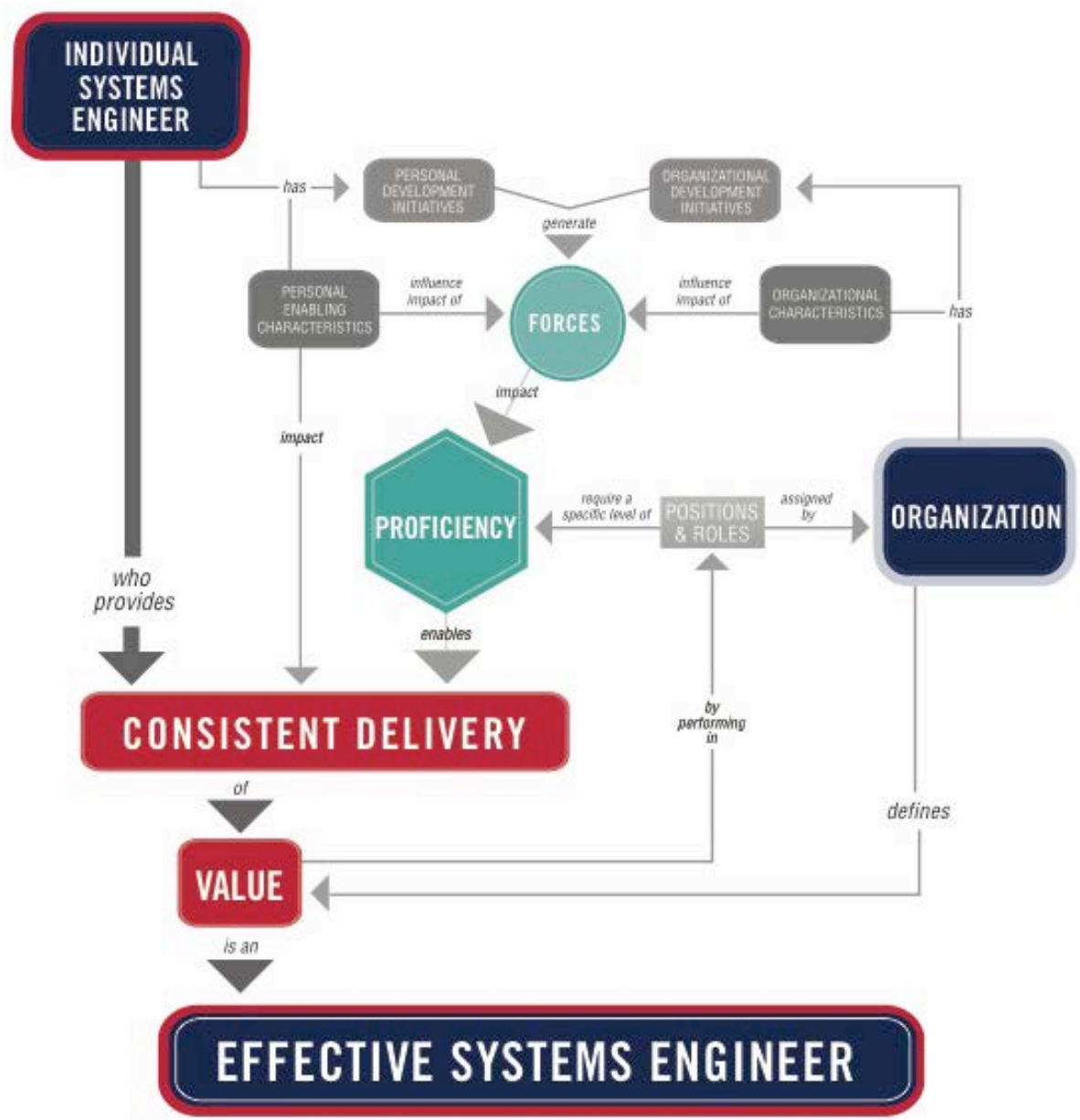
Systems Engineers Organizations: Helix data



Helix & *Atlas*


Project
HELIX
Products
Description of Theory
Atlas 1.0
Details of Development
Supporting Technical Reports
INDIVIDUAL SYSTEMS ENGINEER
CONSISTENT DELIVERY
VALUE
EFFECTIVE SYSTEMS ENGINEER
Enable Assessment
Supporting Tools & Models

Atlas v. 1.0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Values Systems Engineers Provide

A systems engineer who consistently delivers value is effective.

Primary Values Systems Engineers Provide*

- Keeping and maintaining the system vision
- Translation of technical jargon into business or operational terms and vice versa
- Enabling diverse teams to successfully develop systems.
- Managing emergence in both the project and the system
- Enabling good technical decisions at the system level
- Supporting the business cases for systems

- Keeping and maintaining the system vision is enabled by:
  - Getting the "true" requirements from the customer and creating alignment between the customer and the project team. (39%)
  - Seeing relationships between the disciplines and helping team members understand and respect those relationships. (33%)
  - Balancing technical risks and opportunities with the desired end result. (36%)
  - Providing the big picture perspective for the system. (44%)

*Based on most common responses in interviews with systems engineers; validated by interviews with SE managers, program managers, classic engineers.

(%) = percentage of individuals who spoke about keeping and maintaining the vision who described the enabling value.

Examination of Roles

A systems engineering role is a specific set of related systems engineering activities.

Roles are used to define what systems engineers actually do, communicated

To ourselves
To our managers/leaders
To our peers
To our customers

Helix roles data = Participants interviews + resume/CV

- Each position was compared to previously published roles by (Sheard, 1996 and 2000).
- Activities not included in (Sheard, 1996 and 2000) were documented.
- Validations of patterns presented to the systems engineering community
- Validation with peers

The Revised Roles of Systems Engineers

Roles Focused on the System Being Developed:

- Concept Creator
- Requirements Owner
- Systems Architect
- System Integrator
- System Analyst
- Detailed Designer
- V&V Engineer
- Support engineer

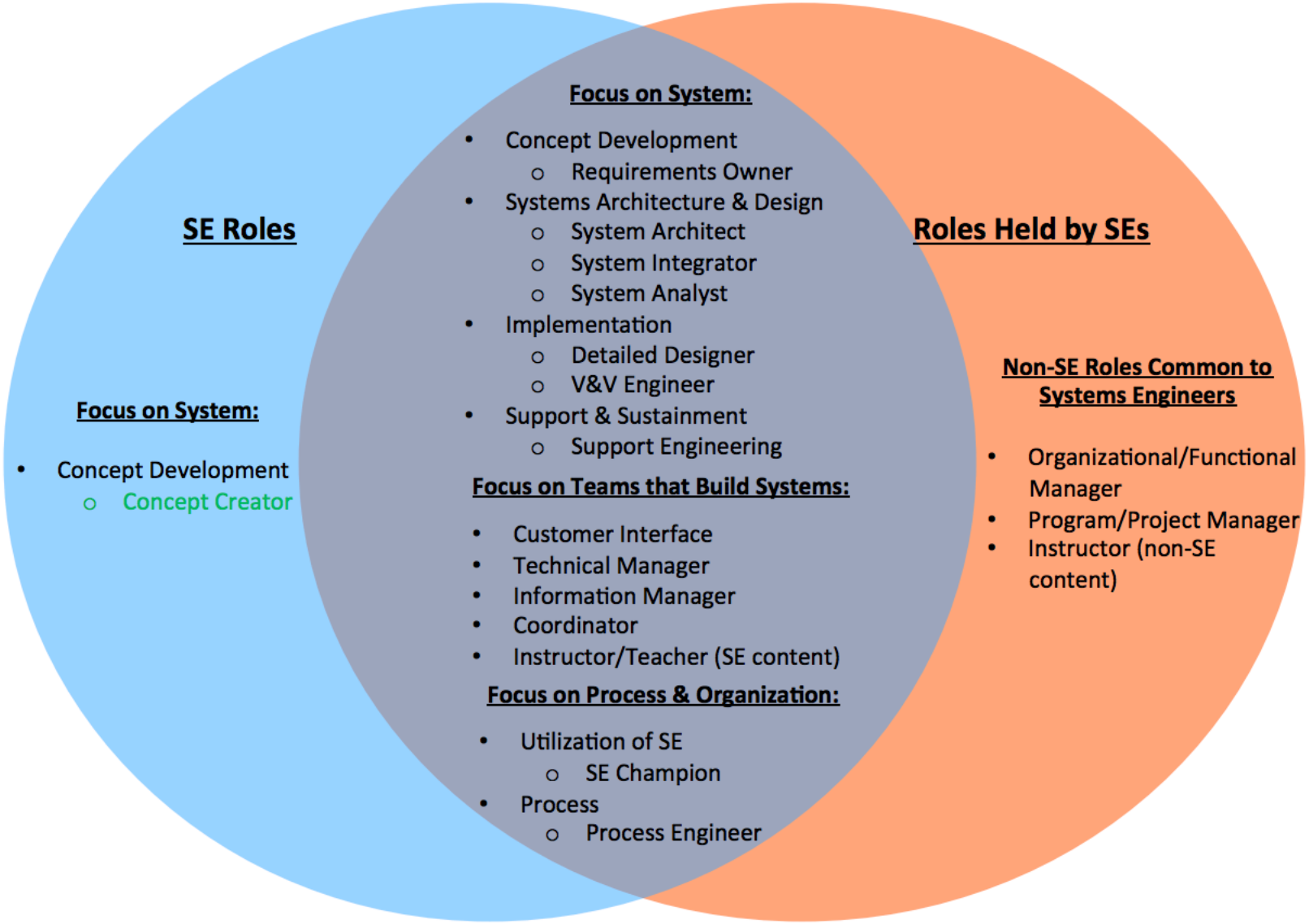
Roles Focused on SE Process and Organization:

- Systems Engineering Champion
- Process Engineer

Roles Focused on Teams That Build Systems:

- Customer Interface
- Technical Manager
- Information Manager
- Coordinator
- Instructor/Teacher

Systems Engineering Roles vs Roles Systems Engineers Play



An Example: One CSE's Roles

Position 1

System Analyst
Detailed Designer

Position 2

System Analyst

Position 3

Requirements Owner
System Architect

Position 4

System Architect
Detailed Designer
Support Engineer

Position 5

Requirements Owner
System Architect
Detailed Designer
V&V Engineer

Position 6

Requirements Owner
Detailed Designer
Technical Manager
Information Manager
Program/Project Manager

Position 7

Detailed Designer
Systems Engineering Champion
Process Engineer

Position 8

Information Manager
Org/Functional Manager

Position 9

Requirements Owner
Detailed Designer
Customer Interface
Coordinator
Org/Functional Manager

Position 10

System Architect
System Integrator
Coordinator

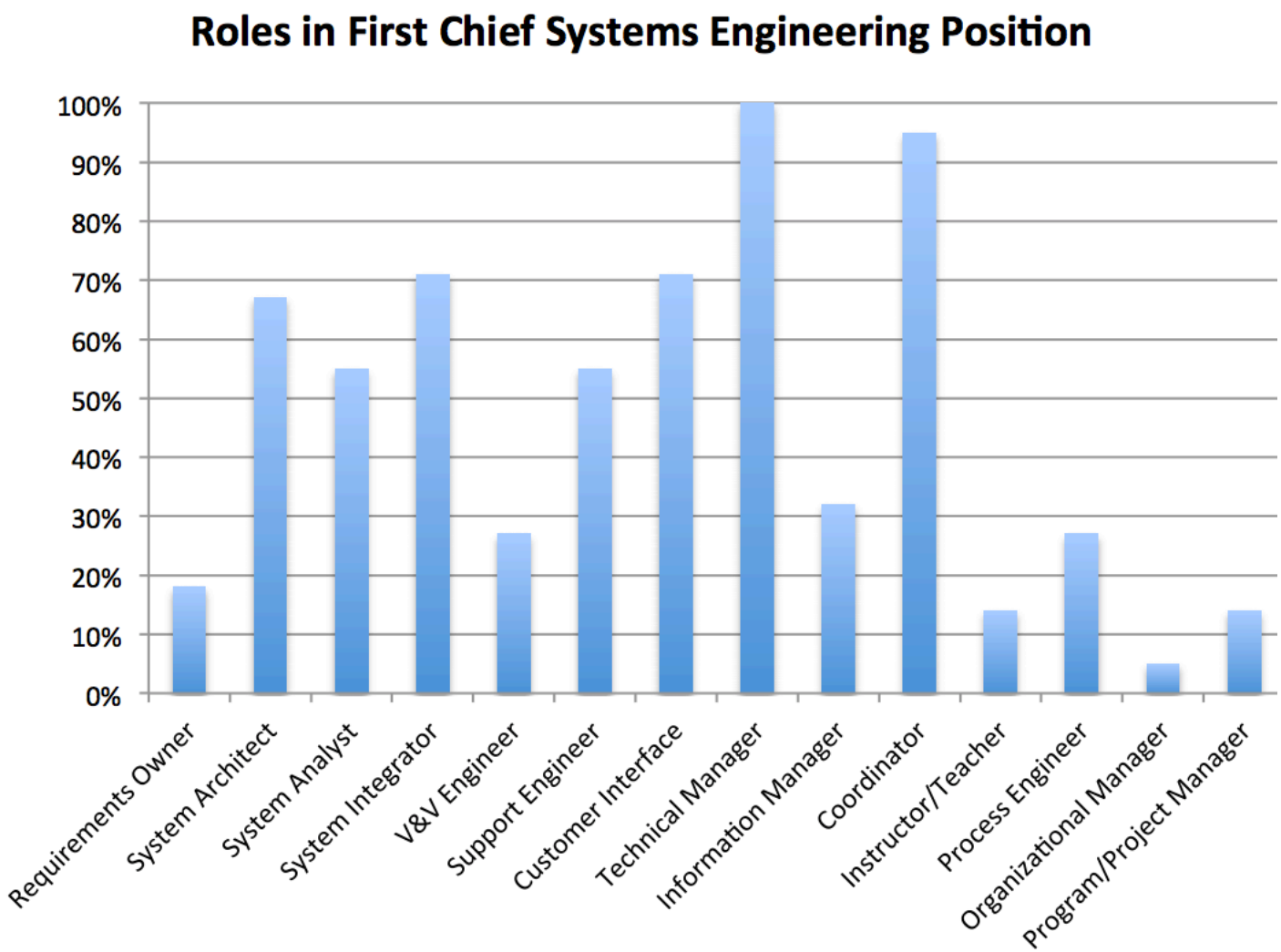
Position 11

System Architect
V&V Engineer
Systems Engineering Champion
Process Engineer
Customer Interface
Technical Manager
Information Manager
Coordinator

Position 12

Instructor/Teacher

Roles in First Chief Systems Engineering Position

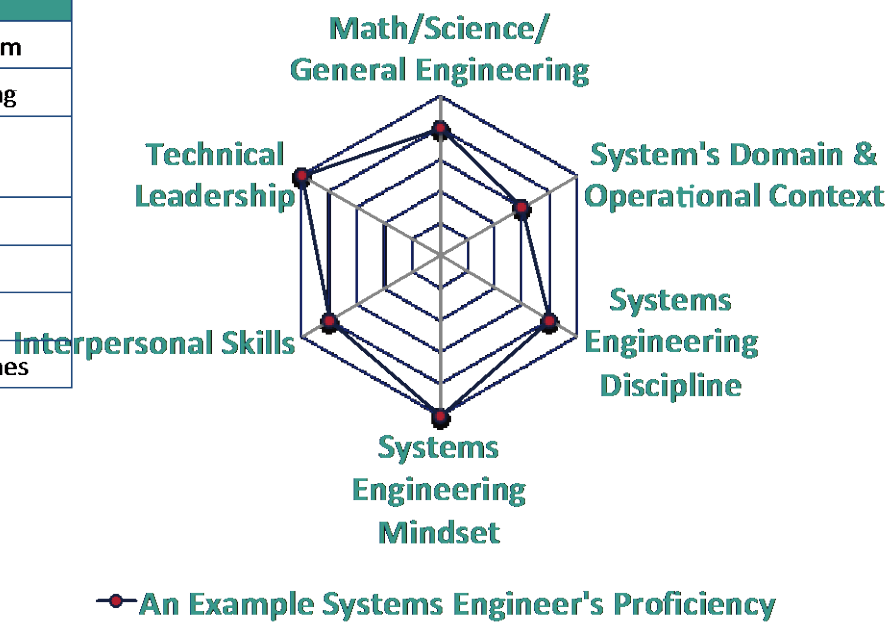


Systems Engineers' Proficiency

Profic ency of a Systems Engineer

6. Technical Leadership
Building & Orchestrating a Diverse Team
Balanced Decision Making & Risk Taking
Guiding Stakeholders with Diverse/ Conflicting Needs
Conflict Resolution & Barrier Breaking
Business & Project Management Skills
Establishing Technical Strategies
Enabling Broad Portfolio-Level Outcomes

1. Math / Science / General Engineering
Natural Science Foundations
Engineering Fundamentals
Probability & Statistics
Calculus & Analytical Geometry
Computing Fundamentals



5. Interpersonal Skills
Communication
Listening & Comprehension
Working in a Team
Influence, Persuasion, & Negotiation
Building a Social Network

2. System's Domain & Operational Context
Principle and Relevant Domains
Familiarity with System's Concept of Operations (ConOps)
Relevant Domains
Relevant Technologies
Relevant Disciplines and Specialties
System Characteristics

4. SE Mindset
'Big Picture' Thinking
Paradoxical Mindset
Flexible Comfort Zone
Multi-Scale Abstraction
Foresight & Vision

3. SE Discipline
Lifecycle
Systems Engineering Management
Systems Engineering Methods, Processes, & Tools
Systems Engineering Trends

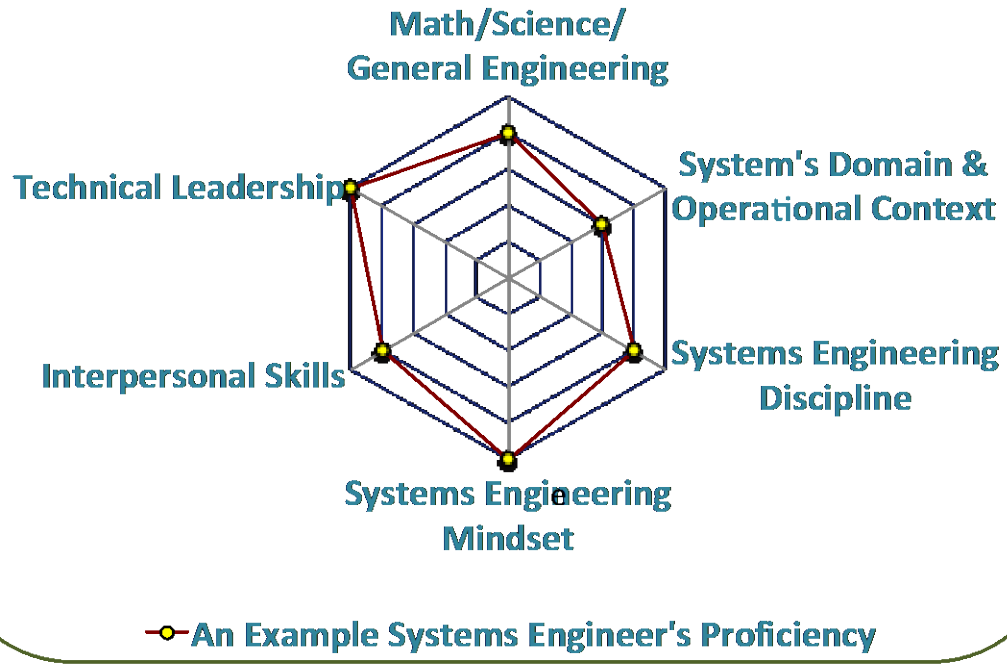
Forces That Impact Proficiency

Forces that Impact Level of Proficiency
(may be generated by Personal and Organizational Development Initiatives)

Experiences	Mentoring	Education & Training

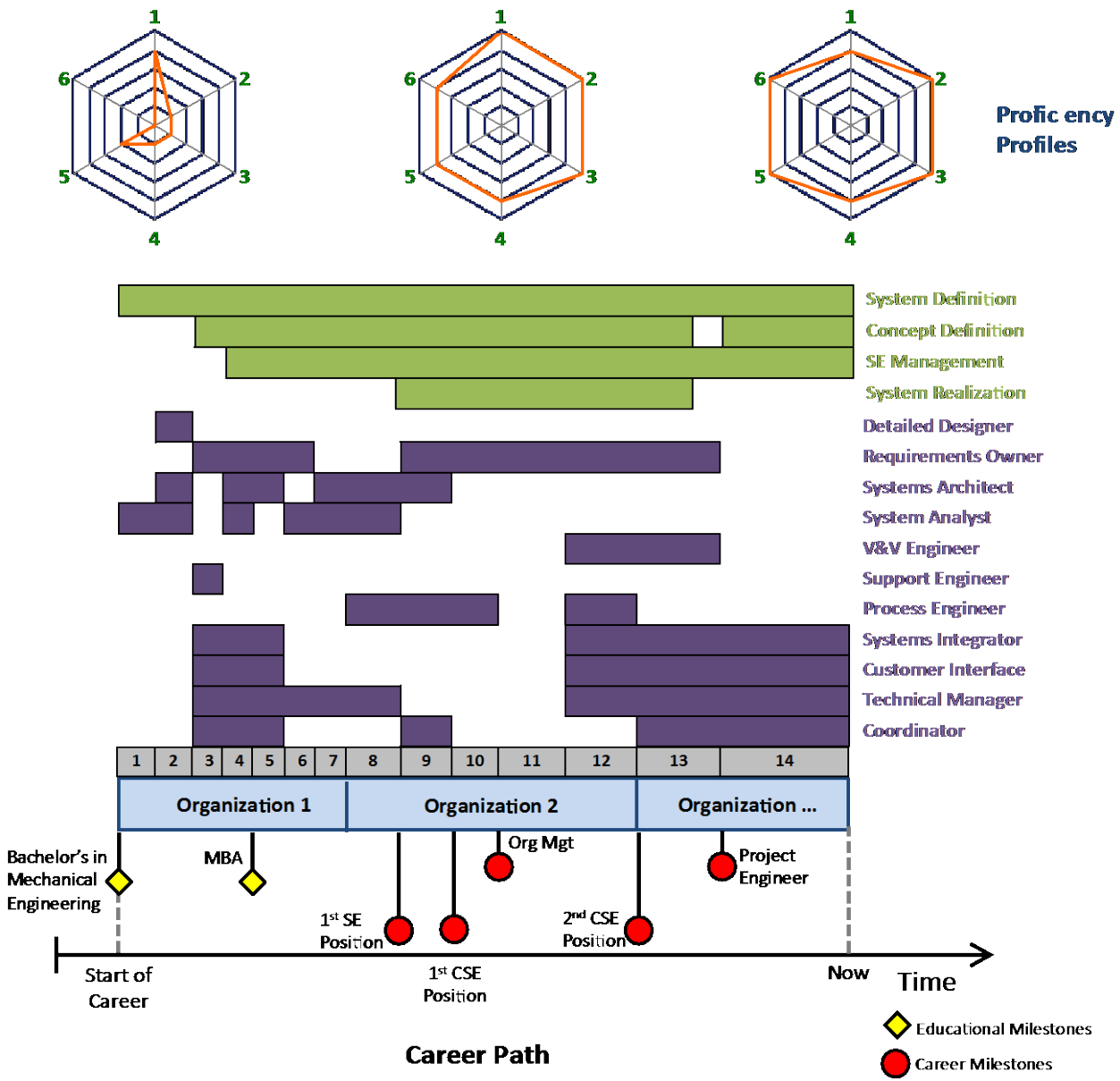
Personal Enabling Characteristics
Self-Awareness
Ambition & Internal Motivation
Inquisitiveness
Lifelong Learning
Confid nce, Persistence, & Focus
Professionalism & Respect
Creativity

Profic ency of a Systems Engineer



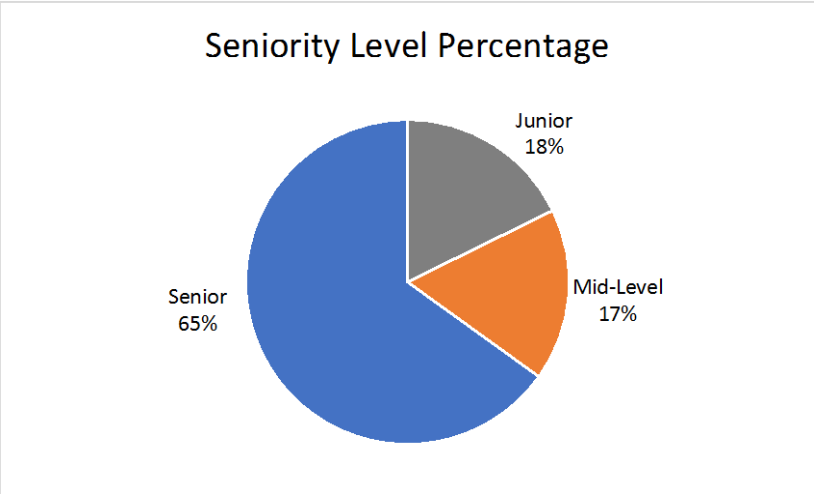
Organizational Characteristics
Culture
Structure
Values
Appreciation of SE
Org. Definition of SE & Systems Engineer
Rewards & Recognitions
Career Growth Potential

Vector: Career Path Analysis Method



Career Path

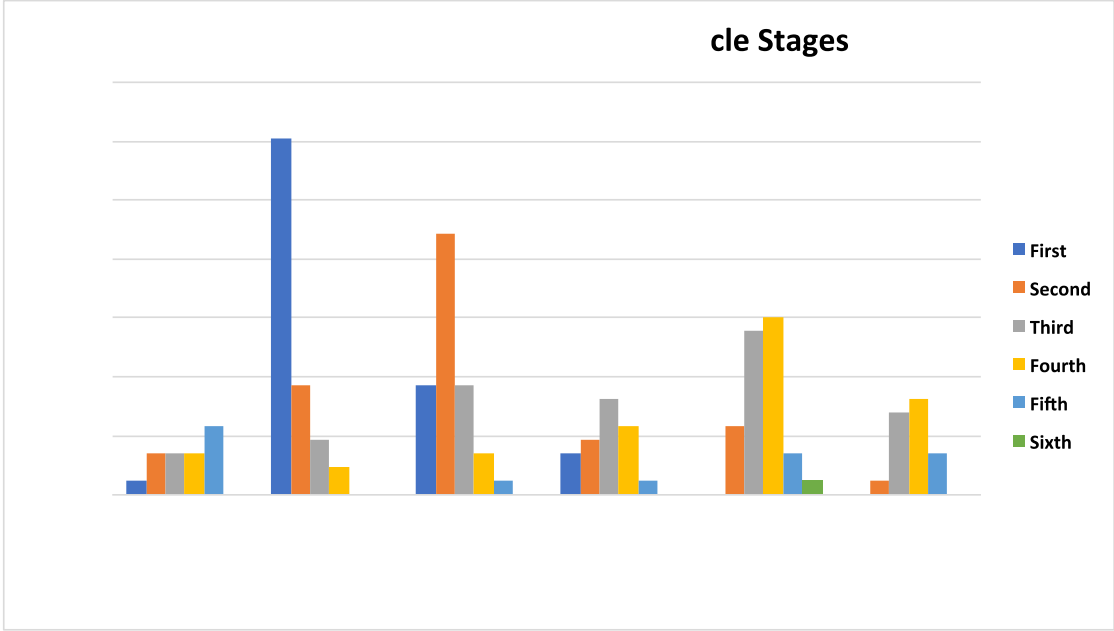
Career Paths

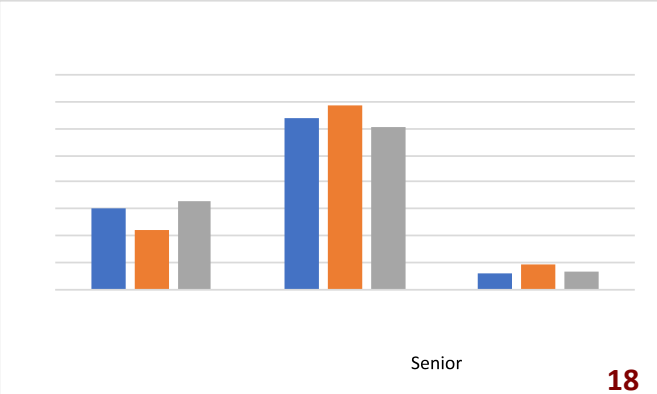


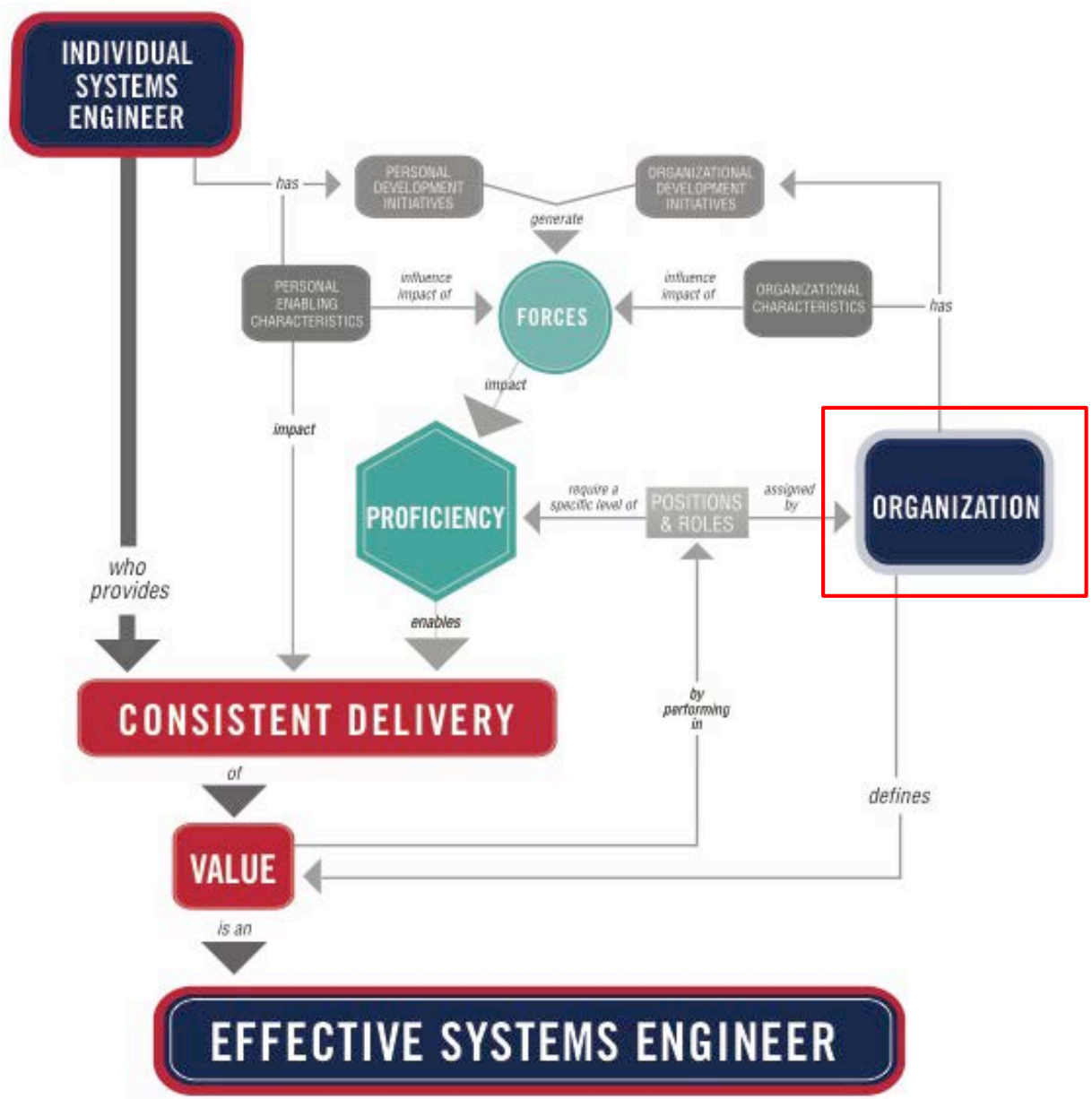
- Role change increments
- Average time in role
- Professional years of experience
- Organizational
- System Scope
- System Type

Still need to define how to:

- Classify SE relevant activities for each role
- Develop Guidebook



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Updated Research Questions

In 2017, Helix focuses on three main research questions:

Research Question 1:

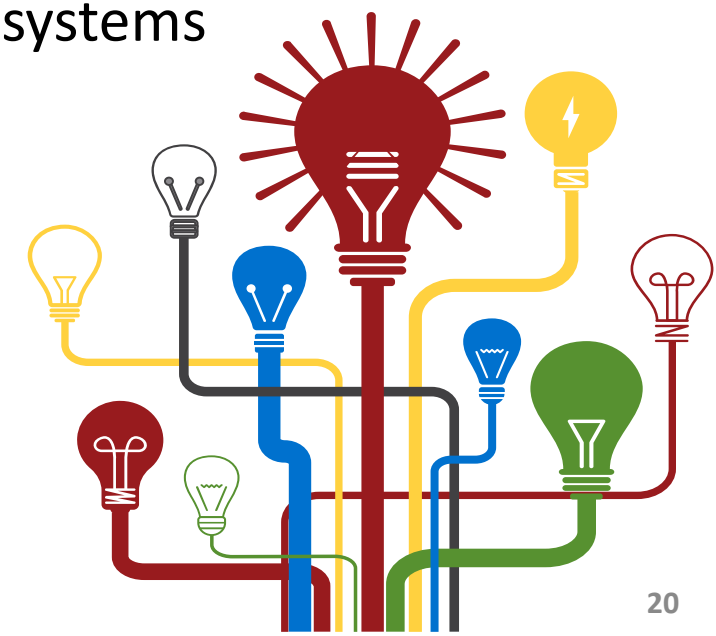
How can organizations improve the effectiveness of their systems engineering workforce?

Research Question 2:

How does the effectiveness of the systems engineering workforce impact the overall systems engineering capability of an organization?

Research Question 3:

What critical factors, in additional to workforce effectiveness, are required to enable systems engineering capability?



What is new in 2017?

- Research has a multi-pronged approach:
  - Additional analysis of existing data
    - Culture
    - Cluster Analysis
    - Semantic Analysis
  - Working with organizations who are implementing findings based on Atlas to gather lessons learned → Implementation Guide
    - Spectrum of implementation: green field to powerful legacy systems
  - Developing a web-based tool set for individual effectiveness
  - Additional analysis on existing data set to:
    - Identify additional patterns on career paths → Guidebook for SE Careers
    - Leading indicators for organizational culture → Implementation Guide, new findings on culture
  - Additional data collection

Helix Going Forward

- In January 2018, Helix will release:
  - Career Path Guidebook
  - Implementation Guide
  - *Atlas* 1.1
    - Updates based on what we've learned in 2018
    - Mapping of *Atlas* to INCOSE draft Competency Framework
- In 2018, Helix hopes to:
  - Continue data collection focused on organizational capability
  - Develop several models (systems dynamics, agent-based, etc.) to support analysis and understanding of organizational systems capability
  - A draft of $Atlas^{ORG}$ – a cohesive theory of what makes systems engineering capabilities effective in an organization

Questions?

Nicole Hutchison

Nicole.hutchison@stevens.edu

helix@stevens.edu

Backups

Helix Progress

- Research Methodology based on a Grounded Theory approach
  - Initially open-ended, exploratory interviews intended to provide a broad variety of data
  - Analysis focused on identifying key patterns and themes
  - Further interviews explored the patterns identified
  - Analysis of career paths to understand the development of Systems Engineers
- **Main focus of Helix 2012-2016 was the creation of *Atlas* – The Theory of Effective Systems Engineers**
  - Version 1.0 released December 2016

Seniority Criteria

Junior	Mid	Senior
≤ 3 Years Experience AND 0-1 formal leadership positions	> 3 and < 20 Years of Experience AND ≥ 2 formal leadership positions	≥ 20 Years Experience OR ≥ 3 formal senior leadership roles (e.g.)
• System Engineer • Requirements Manager • Electronics Engineer • Senior Aerospace Engineer	• IPT Lead • Systems Engineer • Subsystem lead • Control Systems Engineer	• Chief Systems Engineer • Project Engineer • Senior Systems Engineer • Chief Design Engineer
Proficiency in Components	Proficiency in Components and Subsystems	Proficiency in components, subsystems, and systems
Experience in ≥ 2 SE process steps	Experience in ≥ 3 SE process steps	Experience in ≥ 4 SE process steps

Common Enabling Values

- The big picture perspective - enabling system-level technical decisions.
- Projecting into the future, identifying areas of concern for integration in advance, which includes staying “above the noise” of day-to-day development issues and identifying pitfalls.
- Solid grasp on the customer’s needs – leading to “true” requirements – is a critical enabler to ensuring that decisions made will keep the system on the correct technical path. Systems engineers create alignment between the customer and the project team.
- Effectively understanding and communicating the system vision to the team, and ensuring that the team is aligned with this vision. Seeing relationships between the disciplines and helping team members understand and respect those relationships.
- A systems engineer’s problem solving abilities – particularly the ability to focus on root versus proximal cause – is also a key enabler.
- Balancing traditional project management concerns of cost and schedule with technical requirements.
- Understanding the position of a system within the organization or customer’s portfolio and communicating this to the team.
- Translating between stakeholder groups such as customers, internal organizational leadership, and engineering teams.

Approach for Roles Analysis

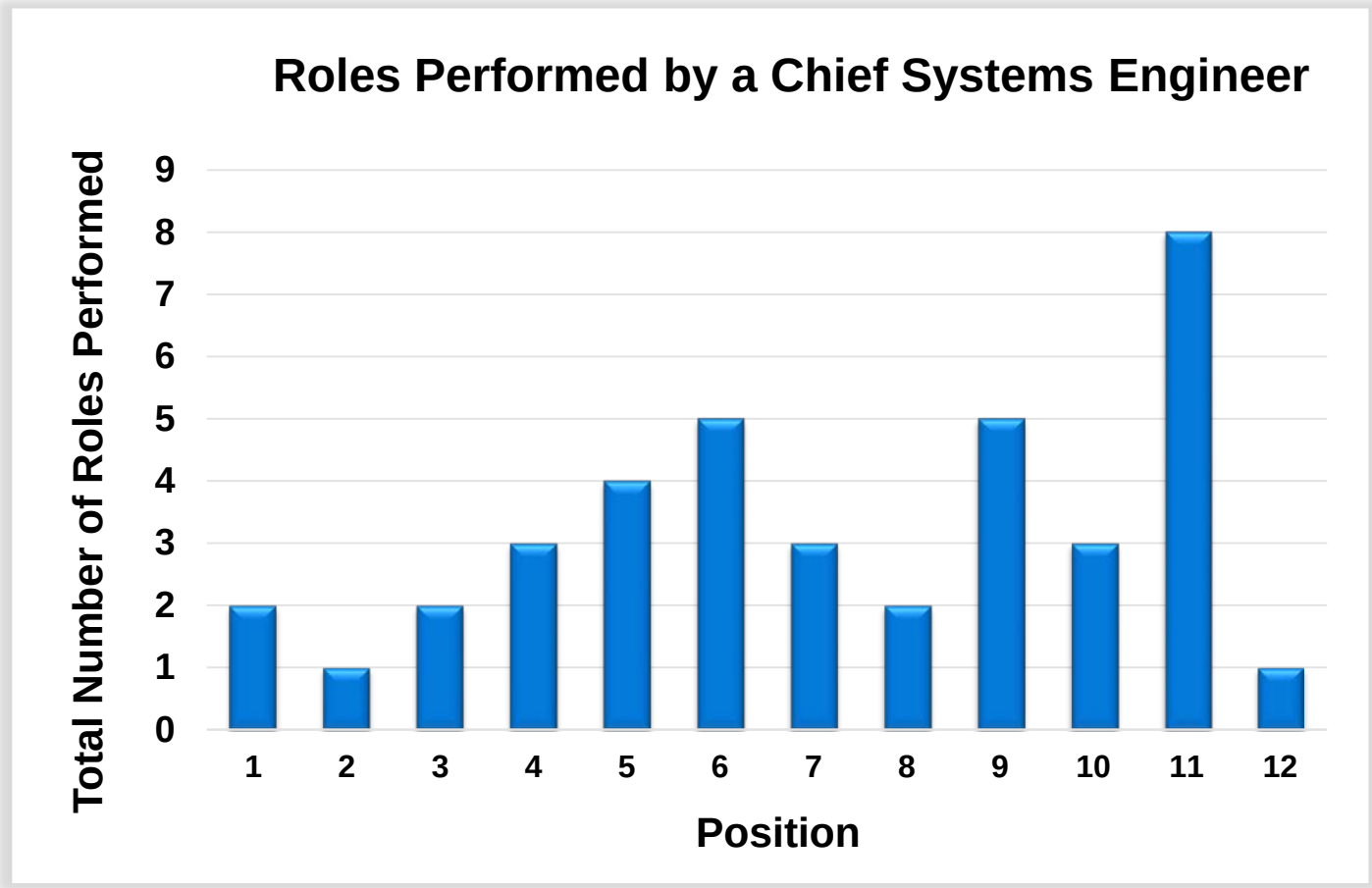
- Collected raw data on activities systems engineers perform
  - Interviews
  - Resumes/CVs
- Analyzed activities compared to Sheard's roles
- Captured activities that did not fit within Sheard's roles → new roles
- Collected community feedback on roles
  - Validation
  - Reactions to titling
  - Desire for structure
- Created a structure for roles

Roles Performed by a Chief Systems Engineer

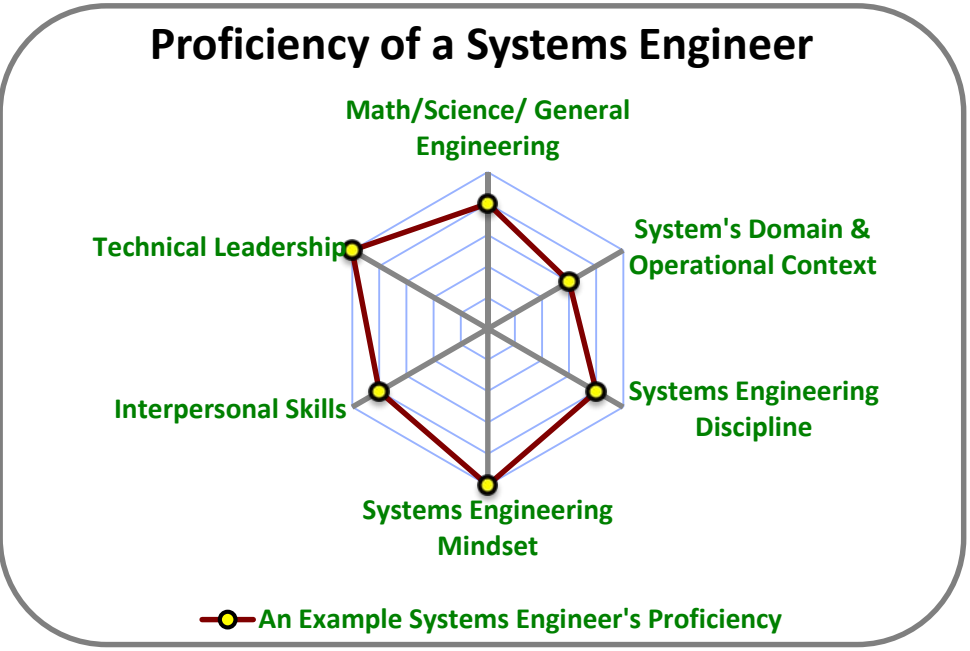
Sample: 1 Chief Systems Engineer

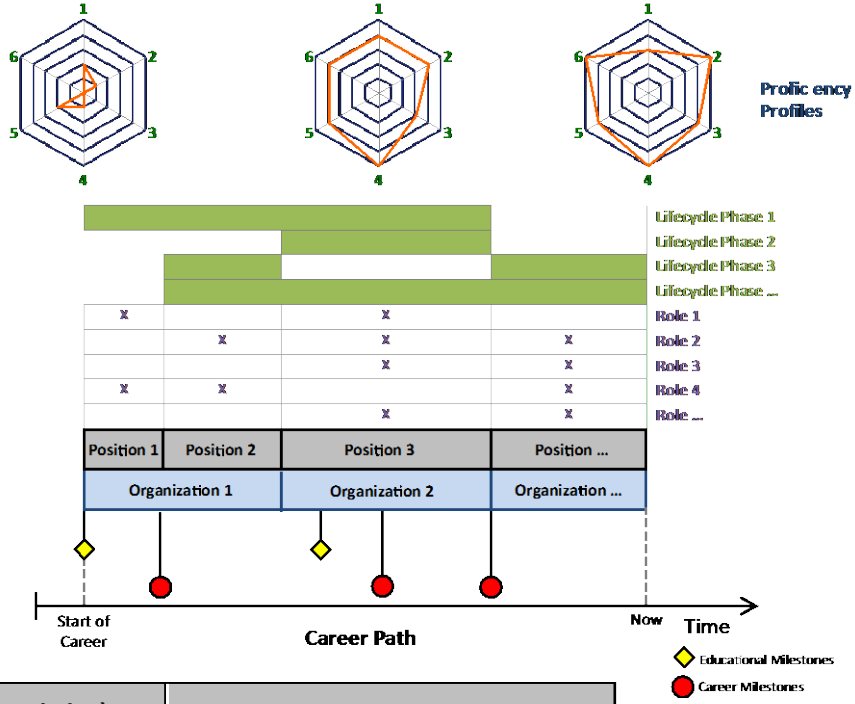
30+ years of experience

Career: 12 Positions



1. What are the characteristics of systems engineers?





Personal Characteristics
Self-Awareness
Ambition & Internal Motivation
Inquisitiveness
Lifelong Learning
Confidence, Persistence, & Focus
Professionalism & Respect
Creativity

Role (Abbreviation)	Role (Abbreviation)
Requirements Owner +	Information Manager (IM) +
System Designer (SD) +	Process Engineer (PE) +
System Analyst (SA) +	Coordinator (CO) +
V&V Engineer (VV) +	Systems Engineering Evangelist (EV) +++
Logistics/ Operations Engineer (LO) +	Detailed Designer (DD) ++
Glue (GL) +	Organizational/Functional Manager (MG) ++
Customer Interface (CI) +	Instructor/Teacher (IN) +++
Technical Manager (TM) +	Program/Project Manager (PM) ++

2. How effective are those who perform SE activities and why?

A systems engineer who consistently delivers value is effective.

Primary Values Systems Engineers Provide*

- Keeping and maintaining the system vision (11%)
- Enabling diverse teams to successfully develop systems. (10%)
- Managing emergence in both the project and the system (7%)
- Enabling good technical decisions at the system level (7%)
- Supporting the business cases for systems (7%)
- Translation of technical jargon into business or operational terms and vice versa (11%)

- Keeping and maintaining the system vision (11%) is enabled by:
  - Getting the "true" requirements from the customer and creating alignment between the customer and the project team. (39%)
  - Seeing relationships between the disciplines and helping team members understand and respect those relationships. (33%)
  - Balancing technical risks and opportunities with the desired end result. (36%)
  - Providing the big picture perspective for the system. (44%)

*Based on most common responses in interviews with systems engineers; validated by interviews with SE managers, program managers, classic engineers. (%) is total number of SErs stating this is a critical value.

(%) = percentage of individuals who spoke a bout keeping and maintaining the vision who described the enabling value.

Helix Insights

3. What are employers doing to improve the effectiveness of systems engineers?

Organizational Characteristics

Organizational Characteristics
Culture
Structure
Values
Appreciation of SE
Org. Definition of SE & Systems Engineers
Rewards & Recognition
Career Growth Potential

Organizational Development Initiatives

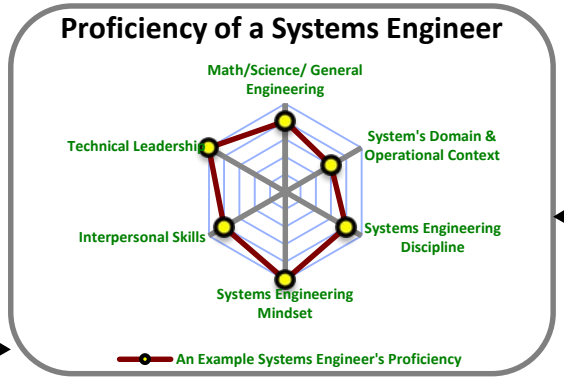
- Rotational Programs
- Mentoring Programs
- High-Potential Programs
- Training Programs
- Educational Programs (assistance or organized cohort)

alignment between

how defined and assigned

Positions & Roles

alignment between



how well initiatives foster proficiencies

Proficiency Areas, Categories, and Topics

Area	Category	Topic
1. Math / Science / General Engineering	1.1. Natural Science Foundations	
	1.2. Engineering Fundamentals	
	1.3. Probability & Statistics	
	1.4. Calculus & Analytical Geometry	
	1.5. Computing Fundamentals	
2. Systems' Domain & Operational Context	2.1. Relevant Domains	
	2.2. Relevant Technologies & Systems	
	2.3. Relevant Disciplines	
	2.4. Familiarity with System's Concept of Operations (ConOps)	
3. Systems Engineering Discipline	3.1. Lifecycle	3.1.1 Lifecycle Models; 3.1.2 Concept Definition; 3.1.3 System Definition; 3.1.4 System Realization; 3.1.5 System Deployment & Use; 3.1.6 Product & Service Life Management
	3.2. Systems Engineering Management	3.2.1 Planning; Risk Management; 3.2.2 Configuration Management; 3.2.3 Assessment & Control; 3.2.4 Quality Management
	3.3. SE Methods, Processes, & Tools	3.3.1 Balance & Optimization; 3.3.2 Modeling & Optimization; 3.3.3 Development Process; 3.3.4 Systems Engineering Tools
	3.4. System Complexity	

Proficiency Areas, Categories, and Topics

Area	Category	Topic
4. Systems Engineering Mindset	4.1. Big-Picture Thinking	
	4.2. Paradoxical Mindset	4.2.1 Big-Picture Thinking and Attention to Detail; 4.2.1 Strategic and Tactical; 4.2.1 Analytic and Synthetic; 4.2.1 Courageous and Humble; 4.2.1 Methodical and Creative
	4.3. Flexible Comfort Zone	
	4.4. Abstraction	
	4.5. Foresight & Vision	
5. Interpersonal Skills	5.1. Communication	5.1.1 Audience; 5.1.2 Content; 5.1.3 Mode
	5.2. Listening & Comprehension	
	5.3. Working in a Team	
	5.4. Influence, Persuasion & Negotiation	
	5.5. Building a Social Network	
6. Technical Leadership	6.1. Building & Orchestrating a Diverse Team	
	6.2. Balanced Decision Making & Rational Risk Taking	
	6.3. Managing Stakeholders and their Needs	
	6.4. Conflict Resolution & Barrier Breaking	
	6.5. Business & Project Management Skills	

Proficiency and Competency

- **Proficiency** is the quality or state of knowledge, skills, abilities, behaviors, and cognition.

- The Helix proficiency model was informed by several other competency models:
  - MITRE *Systems Engineering Competency Model* (MITRE Corporation 2007) (summary)
  - U.S. Department of Defense (DoD) Systems Planning, Research, Development, and Engineering—*Systems Engineer/Program Systems Engineer (SPRDE-SE/PSE) Competency Model* (2007)
  - U.S. National Aeronautics and Space Administration (NASA) *Systems Engineering Competencies* (2009)
  - NASA *Competencies Common to Project Management and Systems Engineering* (2009)
  - INCOSE *Systems Engineering Competencies Framework* (2010)
  - Software Engineering Institute (SEI) *Models for Evaluating and Improving Architecture Competence* (2008)
  - U.S. DoD *DoD Program Management Career Field Functional Competencies* (2007), specifically topic 3 “systems engineering” and topic 4 “software”.

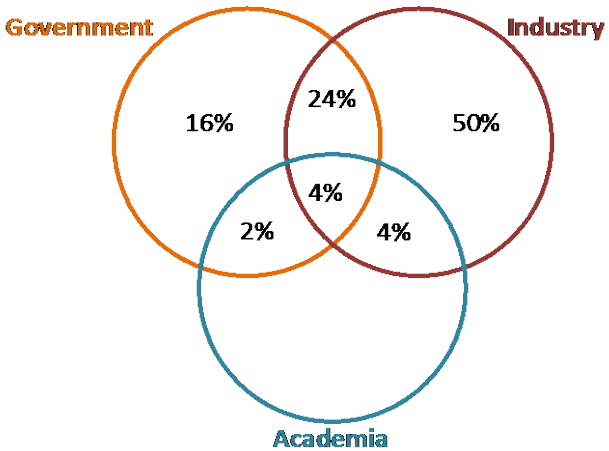
Proficiency Profiles & Career Paths

- The Helix team has helped ~100 systems engineers complete self-assessments of their proficiency & career paths over time.
  - With respect to specific positions (e.g. chief systems engineer, architect, requirements engineer, systems analyst)
  - Beginning of career versus current
  - Organizational expectations for specific positions
- Patterns in proficiency profiles paired with *Vector* career path data to determine patterns for growth
- Individual and organizational data is kept confidential
- Shareable patterns to be published Dec 2016

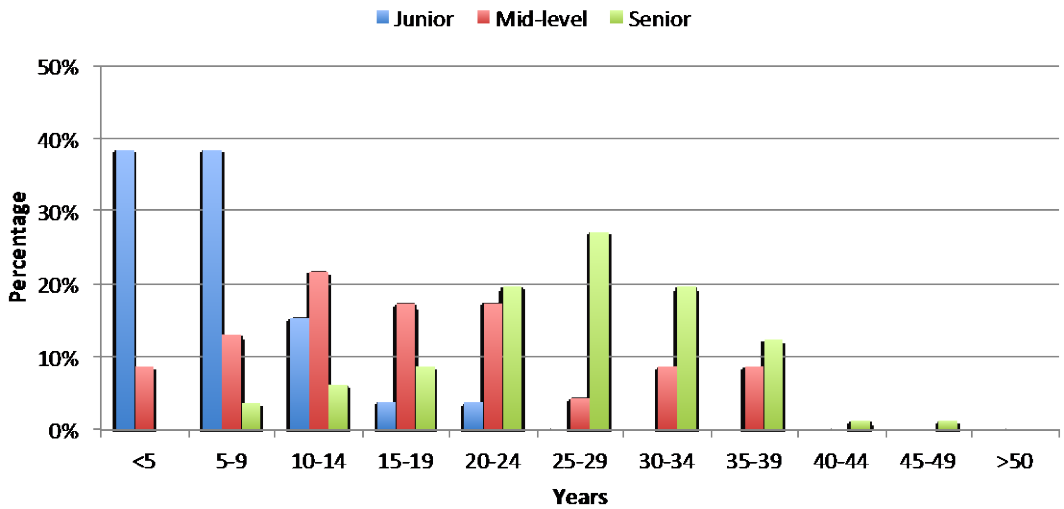
1. What are the characteristics of systems engineers?

Criteria for Determining Criteria of Systems Engineers

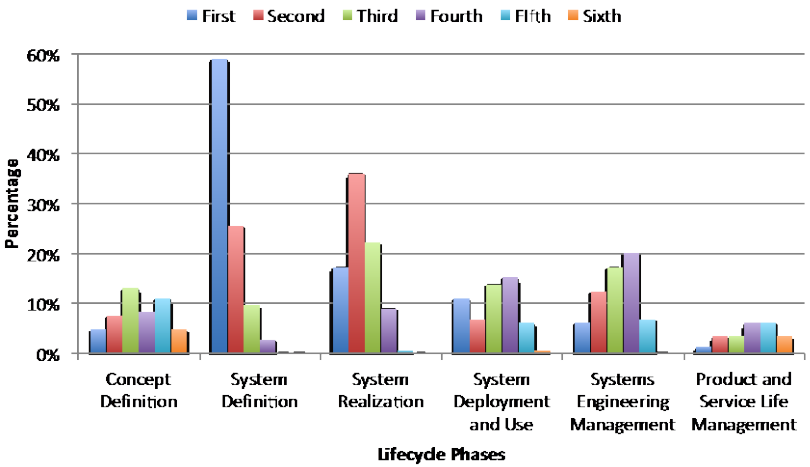
	Junior	Mid-level	Senior
1.	Not more than 1 formal leadership position	At least 2 formal leadership positions	More than 2 formal leadership positions
2.	Experiences primarily in components	Experiences in components and subsystems, and perhaps in systems	Experiences in components, subsystems, systems, and perhaps in systems of systems
3.	Experiences in at least 2 aspects of the systems lifecycle	Experiences in at least 3 aspects of the systems lifecycle	Experiences in at least 4 aspects of the systems lifecycle



Experiences across Organization Sectors



Years of Relevant Experience, by Seniority



Lifecycle Exposure (throughout Career)

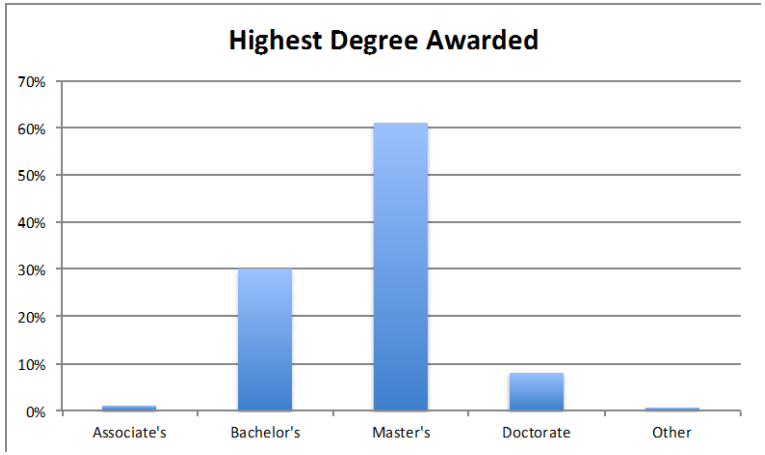
1. What are the characteristics of systems engineers?

Trends in popularity of Bachelor's degree majors:

Major	Before 1980	1980-89	1990-99	2000-09	2010-13
Electrical Engineering	77	168	112	106	5
Mechanical Engineering	17	62	56	63	7
Computer Science	7	47	38	53	5
Aerospace Engineering	8	32	25	32	1
Physics	23	30	25	9	0
Mathematics	27	26	9	15	0
Computer Engineering	2	6	9	33	2

Trends in popularity of Master's degree majors:

Major	Before 1980	1980-89	1990-99	2000-09	2010-13
Systems Engineering	5	5	17	124	87
Electrical Engineering	22	61	75	61	6
Computer Science	7	31	33	39	8
Mechanical Engineering	5	16	31	26	3
Business Administration	4	5	22	21	10
Engineering Management	0	5	22	22	9



Analysis of INCOSE Systems Engineering Professional Applications (n>2,000)

Degree Level	Interview Data				INCOSE Data
	% Junior SErs	% Mid-level SErs	% Senior SErs	% Total	
Associate's	0%	0%	0%	0%	<1%
Bachelor's	44.4%	22.7%	32.3%	33.1%	30%
Master's	55.6%	72.7%	55.6%	58.1%	61%
Doctorate	0%	4.5%	12.1%	8.8%	8%

Highest degree awarded

Web-based Toolset

localhost/Helix/php/registration.php

HELIX

Home About Contact US Help

User Registration For Assessment

1 Step 1 User Profile Form
2 Step 2 Education Form
3 Step 3 Key Training Form
4 Step 4 Career-MileStone Form
5 Step 5 Mentoring MileStone Form

Enter Further Details for Assessment.

First Name

Last Name

Current Title

Department Name: System Engineering

Company Name: SERC

FINISH NEXT PREVIOUS

Type here to search

8:22 AM
7/5/2017

Results Of Hellix Assessm

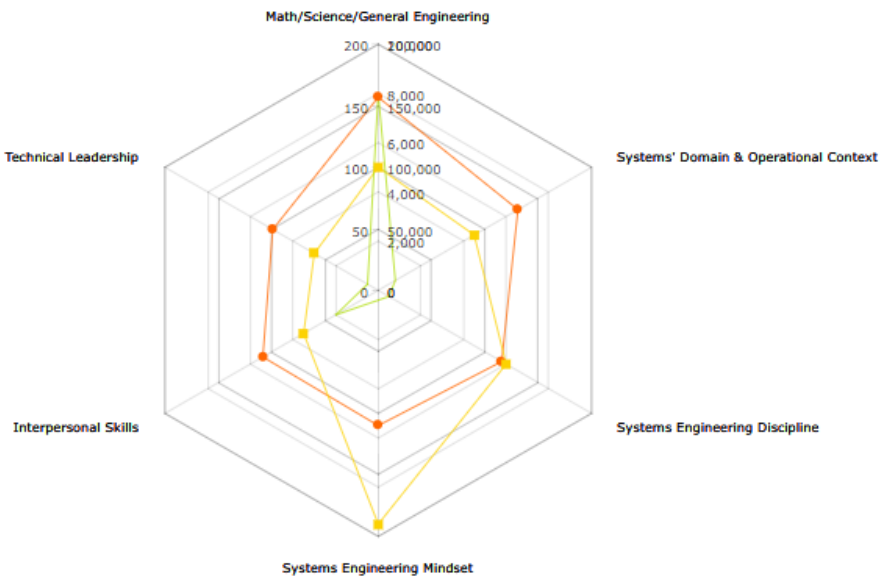
localhost/Helix/php/results.php

HELIX

Home About Contact US User Register Results

Proficiency Profile

- Past
  - POSITION 1
  - POSITION 2
  - POSITION 3
- Current
- Target



Type here to search

Additional Analysis: Career Paths

- Data from additional organizations added to the dataset
- Total of 179 career paths completed.

From complete dataset, we have identified:

- Roles performed throughout career
- Identified seniority level
- Organizational experience
- Total number of organizations
- Experience across domains
- Educational achievements

For Senior participants, we have identified:

- Roles performed throughout career
- Total number of organizations
- Exposure to lifecycle stages
- Educational achievements

Additional Analysis: Organizational Culture

1. Competing Values Framework (Cameron & Quinn)

Flexibility and discretion

Internal focus and integration

Clan	**Adhocracy**
Hierarchy	**Market**

External focus and differentiation

Stability and control

2. Four Places to Look

3. Specific espoused beliefs and actual behaviors

1. **Status**
2. **Structure**
3. **Professionalism**
4. **Formality**
5. **Influence**
6. **Collaboration**
7. **Change**

Additional Analysis: Culture

- We are trying to validate the presence of leading indicators in transcripts.
  - Reviewed 4 transcripts each from 4 different organizations to assess presence of leading indicators
  - Mapped the 7 indicators into NVIVO for 4 transcripts.
- Need to define a process for scoring the categories beyond "present – not present"
- Influence, Collaboration and Change are not often being discussed
  - Updated questions around organization to prompt better responses in this area
- Possibility to expand the mapping to all transcripts from one organization.

Modeling Helix – Future Plans

- Cluster Analysis and Feedback Loop Models
  - Deeper dive into the established proficiencies, forces, and characteristics (both personal and organizational) through cluster analysis, which will help further develop models.
    - Done within the 2017 work
- Modeling Career Path (Individual)
  - Utilize the grounded theory approach to then introduce the dynamism of numerous, both exogenous and endogenous, factors into an individual's career path and how they might best utilize their skill set, environment, and time to enhance their career path.
    - Partially completed with 2017 work
- Multilevel Model and Simulation (Organization)
  - Utilize the grounded theory approach to then introduce the dynamism of numerous criterion for an organization to enhance decision making to implement programs on growing and developing their systems engineering workforce and improve their overall systems perspective through the analysis.
- Ontology
  - With over 6,000 pages of transcript, the team can engage in forming a higher level ontology for the community to have a streamlined discussion where little personal interpretation can be granted, therefore removing some human error.

Additional Data Collection

- 1 new organization has agreed to participate
- 2 additional organizations are considering participation in the US
- 3 participating organizations are considering additional visits
- Satellite data collection
  - 2 non-US organizations have expressed interest in participating
  - Developing protocols for Satellite data collection
    - Team of data collectors in the host country
    - Clear and consistent protocols for data collection
    - Helix team would receive data in some form (in progress – may be aggregate findings, translated summaries, etc.)

2017 Deliverables: Progress to Date

- Implementation Guide
  - Data collection is ongoing
  - Expected completion January 2018
- Career Path Guidebook
  - Data analysis about 75% complete
  - Additional analysis will be incorporated when additional data is collected
  - Expected completion January 2018
- Modeling
  - Foundational work on modeling begun
  - Expected that draft feedback loop, career path, and agent based models will be completed January 2018