



**SYSTEMS**  
**ENGINEERING**  
RESEARCH CENTER

***Atlas Career Path Guidebook:***  
**Patterns and Common Practices in Systems Engineers' Development**

Technical Report SERC-2018-TR-101-C

January 16, 2018

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**Sponsor:** Office of the Deputy Assistant Secretary of Defense for Systems Engineering  
DASD(SE)

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The Systems Engineering Research Center (SERC) is a federally funded University Affiliated Research Center managed by Stevens Institute of Technology.

This material is based upon work supported, in whole or in part, by the U.S. Department of Defense through the Office of the Assistant Secretary of Defense for Research and Engineering (ASD(R&E)) under Contract H98230-08-D-0171 and HQ0034-13-D-0004.

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## EXECUTIVE SUMMARY

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Of the 363 individuals interviewed for Helix, 100% agreed that experiences were the most critical Force for growing systems engineers. Experiences, combined with the additional Forces of Mentoring and Education & Training, make up the career paths of systems engineers.

From 2013 through 2017, the Helix team collected and analyzed detailed information on the careers of 178 systems engineers. The team has conducted a number of analyses on this data, which is reported here.

In particular, this *Guidebook* provides information on:

- The detailed approaches developed to analyze and assess systems engineering career paths. Instructions for individuals or organizations to assess career paths can be found in the companion *Atlas 1.1 Implementation Guide*.
- Patterns in career paths, including findings in terms of education, experiences, and organizations.
- Patterns in the career paths of chief systems engineers (CSEs) in both the Helix dataset and the International Council on Systems Engineering (INCOSE) Systems Engineering Professional (SEP) certification application dataset.
- Frequently asked questions about career paths, which synthesizes statistical findings reported elsewhere in this report. This section interprets preliminary results for the benefit of systems engineering practitioners as well as for systems engineering leaders.
- Insights on relating career paths to proficiency and project performance. This section relates career paths to proficiency in systems engineering. It also describes the relationship between proficiency and project performance.

This *Guidebook* is intended to provide individuals and organizations with critical insights on the patterns of and approaches around systems engineers' career paths.

## 1. INTRODUCTION

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The Systems Engineering Research Center (SERC), a University Affiliated Research Center (UARC), set up by the U.S. Department of Defense (DoD), responded to the systems engineering workforce challenges by initiating the Helix Project to investigate the “DNA” of systems engineers, beginning with those who work in defense and then more broadly. The US Deputy Assistant Secretary of Defense for Systems Engineering (DASD(SE)), the International Council on Systems Engineering (INCOSE) and the Systems Engineering Division of the National Defense Industrial Association (NDIA-SED) jointly sponsor Helix. To ensure Helix delivers the greatest value and to help Helix obtain access to the necessary data, Helix formed the Helix Advisory Panel (HAP) with representatives primarily from those three sponsor organizations. Helix has held four annual workshops with a broad set of representatives from across government, academia, and industry. Helix is a multi-year longitudinal research project, which has gathered data from many organizations with DoD and the Defense Industrial Base (DIB) through a combination of techniques, including interviews with hundreds of systems engineers.

Helix project started in 2012 with the objective to explore DoD and DIB systems engineering workforce. Also, it aims at understanding what makes systems engineers effective and why (Pyster et al. 2013a, 2013b, 2014, 2015 and Hutchison et al. 2016 and 2018). To do so, Helix researchers went through an intensive data collection that involves 287 interviews with systems engineers, peers of systems engineers and their leaders and managers. Resulting data consists of more than 6000 interview transcripts, 270 hours of audio, resumes and curricula vitae. Analysis of Helix aggregated data seeks to identify and examine common experiences among systems engineers. By letting patterns emerge, the Helix team looks to characterize career path patterns between systems engineers.

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### 1.1. WHAT IS A CAREER PATH?

According to systems engineers in the Helix sample, the key forces that help them grow and become increasingly effective are experiences, mentoring, and education and training. Experiences were unanimously reported as the primary force that enables systems engineers to grow. Most often, mentoring was listed as the second-most important force. Education and training were consistently described as important for growth, but less critical than experiences and mentoring. This aligns with Lombardo and Eichinger (1996), whose research on effectiveness in the management field indicated similar results. Though using slightly different terminology, Lombardo and Eichinger stated that lessons learned by successful and effective managers are roughly 70% from experiences, 20% from coworkers/mentors, and 10% from education and training. (1996)

Based on the data from the Helix project, the way that these forces come together throughout an individual’s career makes up an individual’s career path.

***An individual’s career path is the precise combination of experiences, mentoring, and education & training that she goes through during her career, particularly their characteristics, timing, and order.***

This is different from how a career path is often defined in the human resources (HR) community, which tends to be specific to individual organizations. For example, the Society for Human Resource Management (SHRM) defines a career path as, “The progression of jobs in an organization’s specific occupational fields ranked from lowest to highest in the hierarchal structure.” (SHRM 2015) While definitions like this may be useful for classification and management of positions, they are focused more on rigid hierarchy, provide little insight into the growth and development of individuals throughout their careers, and may provide no insight when individuals move between organizations.

A systems engineer will develop abilities that enable her to take on greater responsibility as she progresses in her career, but often will move between professions – for example, moving from electrical engineering to systems engineering – which make traditional HR definitions of career paths obsolete. Understanding an individual’s career path as defined by Helix, however, can provide critical insights into her capabilities. Likewise, understanding how systems engineers build capabilities creates the opportunity to understand patterns in career paths that can be used to guide and grow systems engineers into the future.

Among the forces, *experiences* and *education* were the first chosen for more intensive analysis and are reflected in the career paths reported here. In understanding the forces, the distinction between education and training is nuanced – both involve formal instruction, but “education” refers to instruction at an academic institution that could lead to an academic credential, typically a certificate or degree. While education can focus on a specific subject, it generally is focused on a broader level of understanding. “Training” is generally focused on a more specific topic, method, or approach particular to the individual’s employer. The types of training available or desired are strongly dependent on organizational context.

Because it is often so highly tailored to an organization, few patterns in “training” have been identified across organizations. (Hutchison et al. 2016) Likewise, mentoring is a force for growth that has a place at any point in a systems engineer’s career and the type, availability, and success of mentoring is dependent on not only the organization but also the individuals involved. For these reasons, pattern analysis currently incorporates only data based on experiences and education.

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## **1.2. PURPOSE OF THE *GUIDEBOOK***

The Systems Engineering Career Path Guidebook enables systems engineering leaders and practitioners to identify patterns and common practices in systems engineers’ development and can be used by systems engineering organizations to guide the development of their systems engineers.

The systems engineering workforce benefits from the identification of career path patterns as well as common practices by recognizing critical competencies or proficiencies in systems engineering.

In addition, the guidebook provides a career path extraction methodology based on statistical and text mining principles to be used by systems engineering organizations, systems engineering leaders, and practitioners when needed to identify overarching career patterns in the field of systems engineering. Specific career patterns aim at facilitating systems engineering leaders with confidence when identifying new or potential systems engineers for projects.

Finally, proficient systems engineers improve project performance. The guidebook aims to enable sponsors to identify relationships between career path and proficiency.

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### 1.3. ANTICIPATED USERS

This guidebook is intended to provide guidance to advance individuals' systems engineering capabilities and proficiencies. It is intended for use by any systems engineer and any organization which has identified systems engineering as a critical part of its business and wishes to grow its systems engineering workforce.

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### 1.4. LAYOUT OF THE *GUIDEBOOK*

The guidebook is comprised as the following:

- **Section 2** – *Methodology*, describes the approach developed to identify systems engineering career paths.
- **Section 3** – *Patterns in Career Paths*, presents findings in terms of education, experiences and organizations.
- **Section 4** – *Answering Frequently Asked Questions about Career Paths*, synthesizes statistical findings. This section interprets preliminary results for the benefit of systems engineering practitioners as well as for systems engineering leaders.
- **Section 5** – *Bringing Things Full Circle: Relating Career Paths to Proficiency and Project Performance*. This section relates career paths to proficiency in systems engineering. It also described the relationship between proficiency and project performance.
- **Section 6** – *Conclusions*. Provides a summary of findings, and recommendations.

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### 1.5. COMPANION DOCUMENTS

In addition to this Guidebook, in 2018 the Helix team delivered:

- **Atlas 1.1: *The Theory of Effective Systems Engineers*** – (SERC-2018-TR-101-A) This is an incremental evolution of *Atlas* that reflects feedback from the community, additional

analysis, and maturation of the team’s thinking in 2017. In particular, *Atlas* includes minor updates on the values systems engineers provide, the roles systems engineers play, the proficiency model for systems engineers, and the personal characteristics of systems engineers. Henceforth, this will be referred to as “*Atlas 1.1*”.

- ***Atlas 1.1. Implementation Guide: Moving from Theory Into Practice*** – (SERC-2018-TR-101-C) Whenever *Atlas* is presented, there are many questions about how to take the theory and apply it in practice. The Guide provides examples from organizations that have implemented parts of *Atlas*, and guidance created by the Helix team based on many interactions with organizations around implementation as well as the extensive Helix dataset. Henceforth, this will be referred to as the “*Implementation Guide*”.
- ***2017 Helix Technical Report*** – This document provides an overview of the work completed in 2017 along with the team’s vision and planning for future Helix work. It references, rather than repeats, the findings of the other documents. In addition, it captures the detailed methodologies utilized on the Helix project. (SERC-2018-TR-101)

## 2. METHODOLOGY

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The research methodology adopted for Helix research may be considered to be a modified grounded theory based approach, employing qualitative and quantitative research methods.

From 2012-2014, Helix primarily focused on data collection from DoD and defense industrial base (DIB) organizations through semi-structured in-person interviews with individuals or small groups, continually refining the interview questions and process. Follow-up interviews were conducted, sometimes by telephone with most of the participants. In 2015, the Helix team began to expand the dataset to organizations outside the defense sector to gather additional patterns.

The Helix project adopted a grounded theory approach because it did not presuppose any specific theory or propose any hypotheses at the start of the project. Grounded theory was developed in the social sciences as a method for developing theory that is grounded in data systematically gathered and analyzed (Goulding 2002). Rather than beginning with a hypothesis, the first step is data collection. This approach is unusual in engineering research, where a researcher traditionally begins with a theoretical framework that he or she applies to the phenomenon to be studied.

In the Helix project, the data collected from the many semi-structured interviews were marked up with codes that were grouped into concepts that led to the identification of constructs and categories that formed the building blocks of Atlas. This approach minimized any bias that might be introduced by the researchers, instead allowing the large data set collected through the Helix project to drive theory development.

Qualitative research aims to create or discover what things are made of, and what is created or discovered are called constructs. Qualitative research is useful for obtaining insight into situations and problems on which one has little knowledge a priori. This method is commonly used for providing in-depth descriptions of procedures, beliefs and knowledge, including the opinions of respondents about particular issues; detailed data is gathered through open-ended questions.

Data collection for the Helix project and subsequent analysis of the data was primarily done employing qualitative research methods; appropriate software tools were used to support coding and identification of constructs. Quantitative research begins once initial constructs are in hand. It attempts to gather data by objective methods to provide information about relations, comparisons, and predictions. In the context of the Helix project, quantitative research was performed once initial constructs for demographics of systems engineers, their organizations, and their career paths were established. Data was collected from their resumes as well as through pointed questions during interviews.

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## 2.1. CAREER PATH METHODOLOGY

In addition to the analysis of interview data, the Helix team developed a method for analyzing and visualizing career paths in systems engineering. The career path method presented here supplements the qualitative data analysis described earlier with more quantitative information about an individual's career. This analysis was conducted for 181 systems engineers from a dozen organizations. The initial data collection for career analysis was conducted by:

- Reviewing the resumes submitted by each individual, including chronology, organizations, position titles, and all descriptive text provided within the resumes,
- Reviewing interview transcripts and notes to add detail to the resume data,
- Reviewing the preliminary results during follow up interviews to clarify analysis. Individuals self-selected whether or not they would like to participate in follow-up interviews; roughly half of the individuals in the career analysis sample have participated in follow-up interviews, and
- Comparing the career paths with existing Helix research on the proficiencies of systems engineers and how career path elements may relate to these proficiencies. (Pyster et al. 2014b, Hutchison 2015, Partacz 2017)

By using this approach, the Helix team developed a process to examine experiences and a common framework to capture, analyze, and visualize career paths.

This guidebook illustrates the extractions of career path based on systems engineer's education and experience.

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### 2.1.1. CHARACTERIZING SYSTEMS ENGINEER'S EDUCATION

Education plays two key roles in the development of systems engineers. First, it provides the foundation knowledge to support engineering-related work. Typically, this takes the form of undergraduate education in an engineering discipline, technical field, or physical science. Second, graduate level education is an avenue to develop more advanced skills, explore more in-depth knowledge, and help systems engineers grow as they move through their careers.

To characterize education patterns, the following academic information was extracted for each systems engineer in the sample:

- **Date.** The date of the completion of the degree program.
- **Type of Degree.** This is the level of education an individual achieved. The categories used were: bachelor's, master's, and doctor of philosophy (PhD). For this analysis, only

education that resulted in a degree was recorded. Individuals did receive graduate certificates or took individual courses, but there was not enough data to draw any meaningful conclusions. Also, if a degree was in progress but not completed, it was not recorded.

- **Field of Study.** The primary discipline on which the individual's education was focused. These were initially recorded as reported. Over time, categories of related fields of study were created.

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### 2.1.2.CHARACTERIZING SYSTEMS ENGINEER'S EXPERIENCES

Experimental literature on experiences has primarily focused on two metrics for experience: time (e.g. Ford et al. 1993; Schmidt et al. 1986; Firth 1979; Davidz 2006) and the frequency of times a specific task or activity of interest was performed. Additional literature classifies human subjects based on their experiences – which is subtly different than classifying the experiences themselves – often using a combination of time and the frequency of tasks performed. This approach may also include considerations for specific roles played, (Kor 2003, Kirschenbaum 1992). Additional literature in the field of systems engineering, such as Sheard's "Twelve Systems Engineering Roles" (Sheard, 1996) or the Graduate Reference Curriculum for Systems Engineering (GRCSE) (Pyster et al. 2012) indicate, though, that the characterization of experiences is critically important to understanding how experiences enable growth.

The first challenge is to determine a common "unit of measure" for experience. Though time is common, it is not easily used in the data available. For example, if someone described a position they held over a five-year period, they did not explain the portion of time taken up by the activities they performed over those five years. In addition, several individuals submitted information on their careers that included detailed descriptions, but did not include markers for chronological time. Because of these data limitations, the Helix team chose to use a position as the unit of measure for experience.

Based on both the literature and the Helix data itself, each position has several characteristics:

- **Relevance.** A 'relevant' position is one that enables a systems engineer to develop the proficiencies critical to systems engineering.
- **Position.** Every systems engineer who is employed at an organization fills a position that is established by the organization; that organization also defines the roles and responsibilities to be performed. Helix considers position as a 'unit of measure' for experience, since most of the characteristics of experience are in the context of the position that is held. A 'systems engineering' position is one where the individual's primary focus was on systems engineering activities.



- **Date.** A position typically includes a starting and ending year. It reflects the amount of time spent in a position. Within the data described in Section 3, “current” positions are evaluated up to the year the interview was conducted. For instance, if the current position started in 2014 and the interview was conducted in 2016, the participant is considered to have two years of experience at the current position.
- **Lifecycle Stage.** Generic systems engineering lifecycle phases considered in Atlas are based on the lifecycle phases in the Guide to the Systems Engineering Body of Knowledge (SEBoK) (BKCASE Authors 2015). Phases include: Concept Definition, System Definition, System Realization, System Deployment and Use, Product and Service Life Management, and Systems Engineering Management.
- **Roles.** They described the related systems engineering activities performed at the position held. Helix team identified 16 systems engineering roles which include: Concept Creator, Requirements Owner, System Architect, System Integrator, System Analyst, Detailed Designer, V&V Engineer, Support Engineer, Systems Engineering Champion, Process Engineer, Customer Interface, Technical Manager, Information Manager, Coordinator, Instructor/Teacher.
- **Number of Organizations.** The number of different organizations that an individual has worked at, not counting internal movement within an organization across departments or divisions, reflects the variety of types of experiences that one may possess. The three organizational sectors identified are government, industry, and academia.
- **Systems.** There are many aspects to the types of systems on which a systems engineer could work. Working across these different categories provides valuable experience to an individual systems engineer.
  - **Domain.** This is the primary area of application for the systems being worked on. However, there are many domain categorizations; some domains also relate to industry sectors.
  - **Type.** Product systems, service systems, and enterprise systems are three major types of systems, depending on the nature and composition of the system of interest. System of systems is another paradigm in systems engineering, and could be a combination of one or more types of systems.
  - **Level.** A systems engineer could work on various levels of a system: component/element, subsystem, system, and platform or system of systems.

The ways in which positions were categorized were pulled from existing literature wherever possible. For example, a systems engineer working in the commercial sector of a company may define lifecycle in different terms than those used by a US Department of Defense systems engineer. To normalize the discussion, the definition of life cycle stages from the Guide to the Systems Engineering Body of Knowledge (SEBoK) was used; the interviewee’s own words and

phrasing were compared with the descriptions of life cycle stages in the SEBoK and categorized appropriately (BKCASE Editorial Board, 2014). Likewise, the roles played by the interviewees were based on Sarah Sheard's "Twelve Roles of Systems Engineers" (Sheard, 1996), although roles have been added to reflect what was seen in the data. Where existing literature was not available, categories were created that reflect the character of the data.

By using the data available for each individual, the characteristics of each position and the order that they played them can be identified. Then, the information can be used to develop a preliminary understanding of how career paths shape proficiency.

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### 2.1.3. IDENTIFYING KEY POSITIONS

A third aspect of career paths are the key milestones for a systems engineer's career. The Helix team focused on major steps or changes in a systems engineer's positions. A position is equivalent to the roles and responsibilities associated with an individual's title. Organizations will define what roles and responsibilities each position contains and position descriptions may not translate across organizations. The key positions identified for systems engineer included:

- **First systems engineering position.** This was self-identified by participants as the first position in which systems engineering responsibilities were the primary focus of a position, though they may have non-systems engineering responsibilities as well. This was often difficult to identify, because participants indicated that their roles often transitioned gradually and it was hard to identify when they officially became systems engineers, especially because so many never had that specific title. The Helix team recorded this information in whatever way it was provided by participants. In a few organizations, the hierarchy and structure for becoming a systems engineer was much more well-defined, and for individuals in those organizations, the transition to systems engineer was more easily identified.
- **Chief systems engineering positions.** A chief systems engineer (CSE) is someone who has formal responsibility to oversee and shepherd the technical correctness of a system, often coordinating with many other systems engineers who have smaller scopes of responsibility. These milestones are any positions in which an individual acted as a CSE, regardless of their title within their organization.
- **Project manager positions.** A project manager is someone who has formal responsibility to oversee the programmatic aspects of a system, generally focused on budget and schedule. Project management responsibilities sometimes overlap with SE responsibilities, particularly those around planning and management; in some instances, a CSE may also function as a PM.

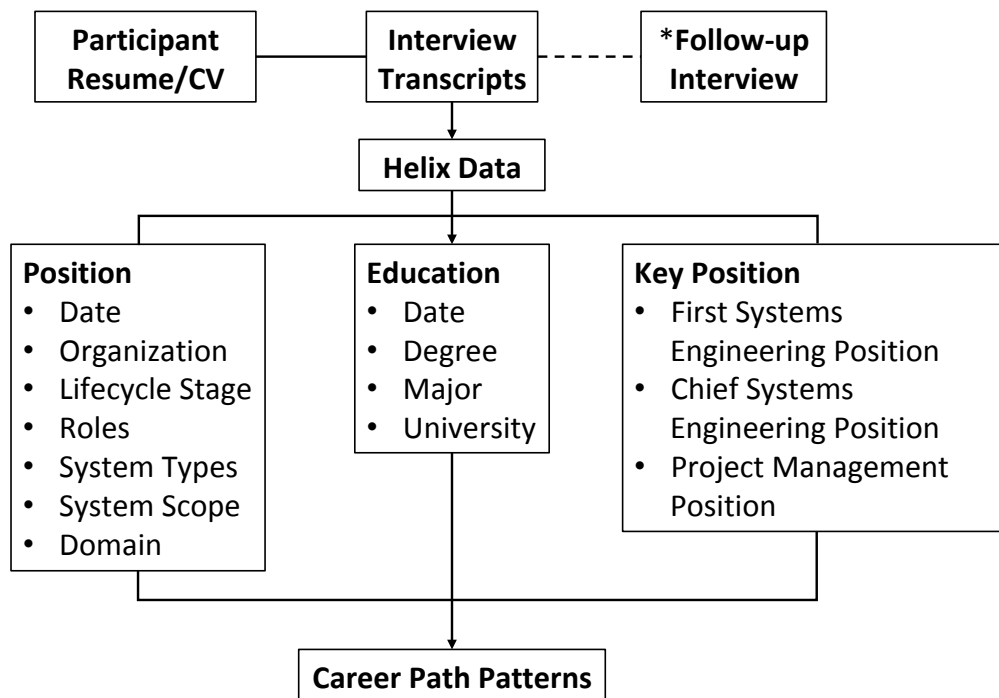
These are not the only positions that could be identified as key. For example, in an organization with an established career path for systems engineers, key positions for that organization

would be expected to be highlighted. This could include positions at different levels of seniority such as “systems analyst” or “systems architect”.

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## 2.2. SUMMARY CAREER PATH METHODOLOGY

Figure 1 illustrates the methodology followed by the Helix team. It starts by collecting data in the forms of resumes or curricula vitae and oral interviews, in some instances a follow-up interview was required to either to clarify or collect more data. The available data is then aggregated and classified into position, education and key position attributes. Analysis on the resulting data through statistical and text mining principles facilitate the identification of patterns.



1

**Figure 1. Helix methodology for career path analysis**

In order to identify and characterize systems engineers, the Helix team created a classification mechanism that ranks systems engineers according to their seniority level. Systems engineers are then classified into Junior, Mid-Level and Senior systems engineers according to: their exposure to leadership positions, experiences at different system levels and lifecycle stages. Leadership Positions is understood as the number of formal leadership positions recognized by an organization. Complexity, which is defined as the level of impact a systems engineer has on the system as well as their experience at the system level. Lifecycle Experience is described as the number of lifecycle stages in which a participant has been involved to. Lastly, Roles is

defined as the total number of positions a systems engineer has performed. Table 1 illustrates the criteria for identifying seniority of systems engineers in the Helix dataset.

**Table 1. Classification rules for assessing the seniority level of systems engineers in the Helix dataset**

| <b>Criteria for Distinguishing the Seniority of Systems Engineers</b> |   |  |  |
|---|---|--|--|
| <b>Criteria</b>   | <b>Junior</b>   | <b>Mid-level</b>   | <b>Senior</b>  |
| <b>Leadership</b>   | Primarily works as an individual contributor; has had zero or one formal leadership positions, which can be as an official supervisor or as a task leader                 | Has had at least two formal leadership positions over teams or tasks of significant size and scope; viewed as a leader in a project, program, or business unit of the larger enterprise  | Three or more formal leadership positions over teams or tasks of significant size and scope, including second-level management roles; viewed as a leader in the enterprise   |
| <b>Complexity</b>   | Relevant experiences on a simple project, system, or task, working primarily at the system components level or simple activities such as managing a requirements database | Relevant experiences on moderately complex projects or systems, working at the sub-system and system levels or on moderately complex activities such as managing the development and negotiation of requirements for a moderately complex system | Relevant experiences on complex projects or systems, working at the system and platforms/systems of systems levels or on quite complex activities such as managing the development and negotiation of requirements for a complex system of systems |
| <b>Lifecycle</b>  | Relevant experiences in at least two phases of the systems lifecycle  | Relevant experiences in at least three phases of the systems lifecycle   | Relevant experiences in at least four phases of the systems lifecycle  |
| <b>Roles</b>  | Worked on up to 3 different roles   | Worked on 4 to 6 different roles   | Worked on 7 to 15 different roles  |

Section 3 discusses career paths in systems engineering based on junior, mid-level and senior systems engineers.

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### 2.3. ASSESSING YOUR CAREER PATH

In addition to reading the information provided here, an individual may choose to assess his or her own career path. The specific instructions for this are provided in the *Atlas 1.1 Implementation Guide*, and mirror the methodology described above. Helix provides two tools for this: one is a paper-based career path template (see Appendix C) and the other is an Excel-based template available at <http://www.sercuarc.org/projects/helix>. It is worth noting that in addition to the areas for which there were clear patterns, which are reported in Section 3, there are other areas of career paths that individuals or organizations may wish to assess. These include:

- **Identifying Key Training.** For some individuals in the Helix dataset, there were a few key training opportunities that really stood out as helping them grow. These included trainings such as week-long leadership retreats or two-week rotations into other parts of the organization. The idea here is not to catalogue every training course you have ever taken, but to highlight training that has been particularly impactful and put it on a timeline with your positions.
- **Identifying Key Mentoring.** As with training, mentoring comes in many different forms. For the career path, it is useful to identify areas where mentoring was particularly prevalent and can be tied directly to growth. Examples in the Helix dataset included shadowing where a senior systems engineer sat down and explained all of the ins and outs of a legacy system or more senior systems engineers guiding individuals on how to deal with a particular customer or facet of systems engineering.
- **Creating a Career Path Timeline.** Visualizing the career path can in some ways be just as helpful as the analysis described above. It is the opportunity to put all of the disparate pieces of your career path together and look at them more holistically. In working with individuals to create their self-assessments, the Helix team heard things like, “Wow. I thought I had played a lot of different systems engineering roles, but looks at this, I need to diversify more,” or “I had thought I had spent plenty of time in requirements, but now that I look at this, it has only been a small part of my career.”

This is not to say that there is a “right” or “wrong” career path – but this holistic view allows you to identify gaps or overlaps in a clear way. It also provides you the opportunity to more intentionally plan your career path for the future. For example, a gap in a systems engineering role may encourage you to focus on a different project or type of work than you otherwise might. And it should be noted that gaps are not “bad”; most career paths did not include all 15 roles. But again, it allows you to determine whether this is acceptable based on your goals or whether this is something that should be addressed.

Figure 2 provides an example of a career path assessment and as illustrated in the figure, pairing the career path with proficiency assessments can provide additional insight.

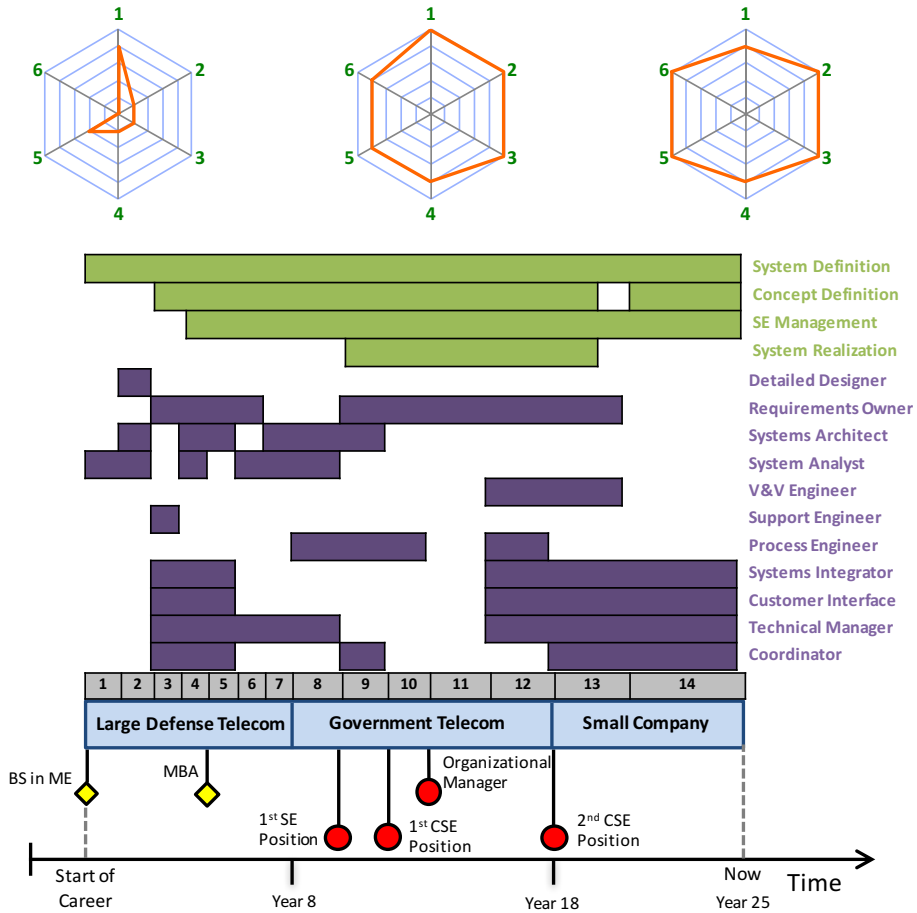


Figure 2. Example career path of a chief systems engineer from the Helix sample.

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## 2.4. THE HELIX DATASET FOR CAREER PATHS

Helix research uses a bottom-up approach, based on the data being analyzed. Hence, it is essential to gather data that is sufficient in quantity and quality to enable effective development of *Atlas*, and to provide reliable insights and recommendations that can be confidently used for the development of effective systems engineers.

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### 2.4.1. DATA SOURCES

The primary source of data for Helix research is face-to-face semi-structured interviews with participants at their place of work. Additional information about the participant and the organization were also collected as available. Another data source that Helix gained access to was the application data for the INCOSE Systems Engineering Professional (SEP) certification program.

## **Helix Interview Data**

From June 2013, when Helix conducted its first site visit for data collection, through the most recent data collection in November 2017, a total of 363 participants were interviewed from 23 organizations. Typically, 2 to 3 members of the Helix team interviewed anywhere from 1 to 6 participants in a single interview session.

Interview participants, if willing, also provided their resumes with details about their educational background, work experiences, and any other information they wished to provide.

Follow-up interviews were conducted over telephone with willing participants, to explore topics that could not be covered in the initial face-to-face interviews or to collect additional information based on their resumes. Follow-up interviews were also used to validate results of Helix analysis.

In both the initial interviews as well as follow-up interviews, transcripts were created when audio recording was permitted; when not permitted, summaries were prepared from notes taken during the interviews. These transcripts and summaries from a total of about 270 hours of interviews form the bulk of data that Helix analyzed.

The data that was analyzed for *Atlas 1.1* and presented in this report reflects a sub-set of interviewees. This is because not all individuals provided enough information to complete a career path assessment. Subsequent reports will include additional analysis performed on the Helix interview data.

## **INCOSE SEP Application Dataset**

INCOSE provides three different levels of SEP certification: Associate (ASEP), Certified (CSEP), and Expert (ESEP). Applicants from all over the world seeking INCOSE certification apply for the appropriate level based on their systems engineering experiences, knowledge, and accomplishment. INCOSE provided to Helix, under a Non-Disclosure Agreement, over 3000 application forms received from applicants during the period May 2004 to May 2014. Though the application data was available in electronic form, it was not in a format that would readily support analysis. Significant time and effort was spent in extraction, cleaning, and tabulating the data to enable further analysis.

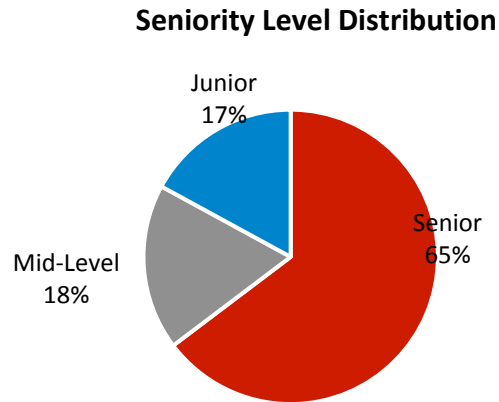
Analysis of INCOSE data did not directly contribute to the building of *Atlas*, but provided some validation and additional insights for the analysis of the interview data.

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### **2.4.2.DEMOGRAPHICS OF HELIX DATASET**

Understanding the sample population is important, since the interview data is reflective of the population from which it has been collected, and in turn, that data is the basis for identifying career paths. Following the rubric for understanding the seniority of systems engineers

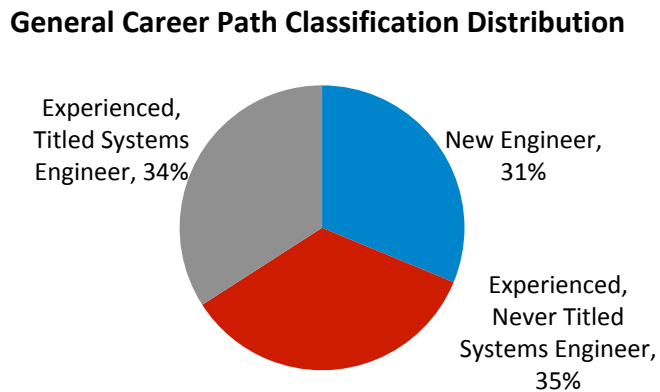
presented in Table 1, the results are presented in Figure 3. Senior participants cover almost two-thirds of the population while the remaining one-third is almost split almost evenly between junior and mid-Level participants.



**Figure 3. Distribution of seniority levels across Helix dataset**

Figure 4 illustrates the distribution of participants based on the “general career path classifications” used in Partacz (2017). It divides the sample by individuals who are recognized – and recognize themselves as systems engineers – and those who do not. A third category “new engineer” denotes any individual with less than nine years of experience. Note that this is different than the Helix seniority classifications, which do not depend on time.

It can be observed that more than two-thirds of Helix participants are Experienced Systems Engineers. New Engineers are slightly behind Experienced Systems Engineers with only 31% of the participants being allocated to New Systems Engineers. On the other hand, an almost even distribution occurred among Experienced Systems Engineers who have never been officially titled “systems engineer” and those who have.



**Figure 4. Distribution of career path classification across Helix dataset**



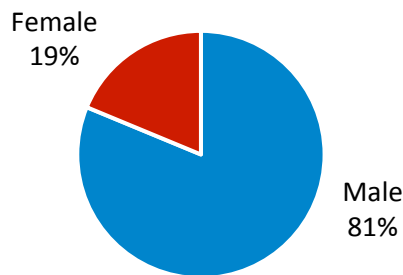
Figure 5 denotes the distribution of gender across the Helix dataset. It can be observed that more than three-fourths of participants are male systems engineers. In each organization, the Helix team requested additional information on the overarching systems engineering workforce – as opposed to only the sampled individuals. Most organizations could not or chose not to provide this information. The Helix team does not know if the demographics of the sample reflect the overarching gender demographics of the populations or is a result of the way in which organizations selected individuals for participation.

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#### 2.4.1. DEMOGRAPHICS OF CAREER PATH DATASET

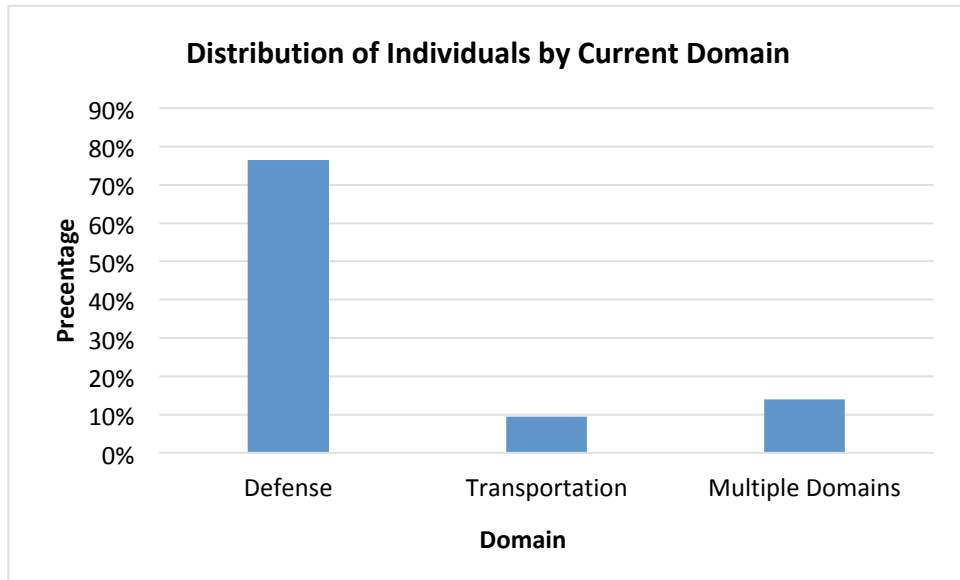
From June 2013, when Helix conducted its first site visit for data collection, through the most recent data collection in November 2017, a total of 363 participants were interviewed from 23 organizations. However, the analysis conducted here is based on complete data of 178 participants from 13 organizations. Not all individuals provided enough detail for the team to create a career path. The most successful career path completion included

**Participants Gender Distribution**



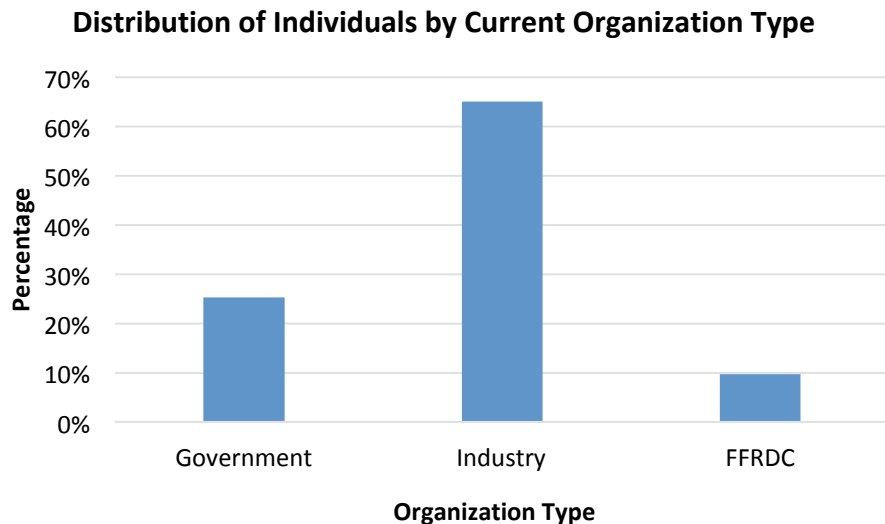
**Figure 5. Distribution of genders across Helix dataset**

To provide a more detailed context about Helix findings, it is helpful to understand the domain in which the systems engineers interviewed perform their activities. As it can be observed in Figure 6, from every four participants, three are related to Defense organizations. Multiple Domains domain include organizations that have such varied business portfolios that no single one could be selected.



**Figure 6. Individuals by current domain**

Another classification of the type of participant organizations is their commercial affiliation. Helix classified commercial affiliation into: Government, Industry and Federally Funded Research and Development Centers (FFRDC). As it can be observed in Figure 7, more than half of the participants belong to industry organizations. The rest of the dataset is distributed among government entities and FFRDC, the former covering 10%, while direct government organizations cover one-quarter of the analyzed dataset.



**Figure 7. Individuals by current organization type**

## 2.4.2. DEMOGRAPHICS OF INCOSE SEP APPLICANTS

From the pool of application forms received by the Helix team, about 2500 unique applicants were identified for further analysis. The filter applied was whether or not the individual's information was complete and whether they had received certification. The rationale was that individuals who were failed to complete certification process may have done so based on their career paths not meeting the INCOSE requirements.

**Table 2. Geographical Distribution of INCOSE SEP Applicants**

| Rank | Country | # of Applicants | % of Total |
|------|---------|-----------------|------------|
| 1.   | U.S.    | 1847            | 74%        |
| 2.   | India   | 179             | 7%         |
| 3.   | Germany | 151             | 6%         |
| 4.   | France  | 101             | 4%         |
| 5.   | U.K.    | 49              | 2%         |
| 6.   | Sweden  | 41              | <2%        |
| 7.   | Spain   | 36              | 1%         |
|      | Other   | 100             | 4%         |

These applicants were predominantly from the U.S, but there were others from Asia and Europe as well, as indicated in Table 2.

The INCOSE SEP application data did not include gender. It did include date of birth, from which the Helix team extrapolated the applicant age at time of application, which is reflected in Table 3. Not that the average age was consistent year by year.

**Table 3. Average Age of INCOSE SEP Applicants by Certification Type**

| AGE   | CERTIFICATION TYPE |      |      |
|-------|--------------------|------|------|
|       | ASEP               | CSEP | ESEP |
| 20-25 | 15%                | 1%   | 0%   |
| 25-30 | 26%                | 3%   | 0%   |
| 30-35 | 21%                | 16%  | 0%   |
| 35-40 | 13%                | 15%  | 0%   |
| 40-45 | 15%                | 15%  | 1%   |
| 45-50 | 0%                 | 18%  | 11%  |
| 50-55 | 4%                 | 16%  | 33%  |
| 55-60 | 2%                 | 9%   | 26%  |
| 60-65 | 4%                 | 5%   | 17%  |
| 65-75 | 0%                 | 2%   | 11%  |
| 75-90 | 0%                 | 0%   | 1%   |

Information from all the 2504 unique applicants was used for analysis of education background; a subset of those applicants was analyzed for experiences, including all of the certified ESEP applicants and a selection of the ASEP and CSEP applicants. The reason the full dataset was not used for experience analysis was the high level of cleaning required to create consistency in the dataset.

### 3. PATTERNS IN CAREER PATHS

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Two of the most common questions the Helix team receives are, “How can I grow as a systems engineer?” and “How can I grow the systems engineers in my organization?” The first way the Helix team addresses these questions is by examining the career paths of systems engineers in the dataset.

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#### 3.1. EDUCATION

Education patterns are related to the background knowledge acquired through the years that facilitates and supports the execution of systems engineering activities. The Helix team started by characterizing all the completed academic degrees, in chronological order. Then, the team categorized achieved degree into bachelor’s and master’s level. Next, degrees were clustered into similar fields. For instance, “Computer Engineering” was combined with “Computer Science” this facilitated the visualization of bachelor’s and master’s degrees earned.

Figure 8 illustrates the differences between the majors at the graduate and undergraduate levels in the sample. Most of the degrees conferred at the undergraduate level are Science, Technology, Engineering and Mathematics (STEM) related degrees. There are only limited instances where the area of expertise is liberal arts, or other non-technical degrees. On the other hand, at the graduate level, Systems Engineering, Business Administration and Electrical Engineering cover more than two-thirds of the total master’s degrees conferred.

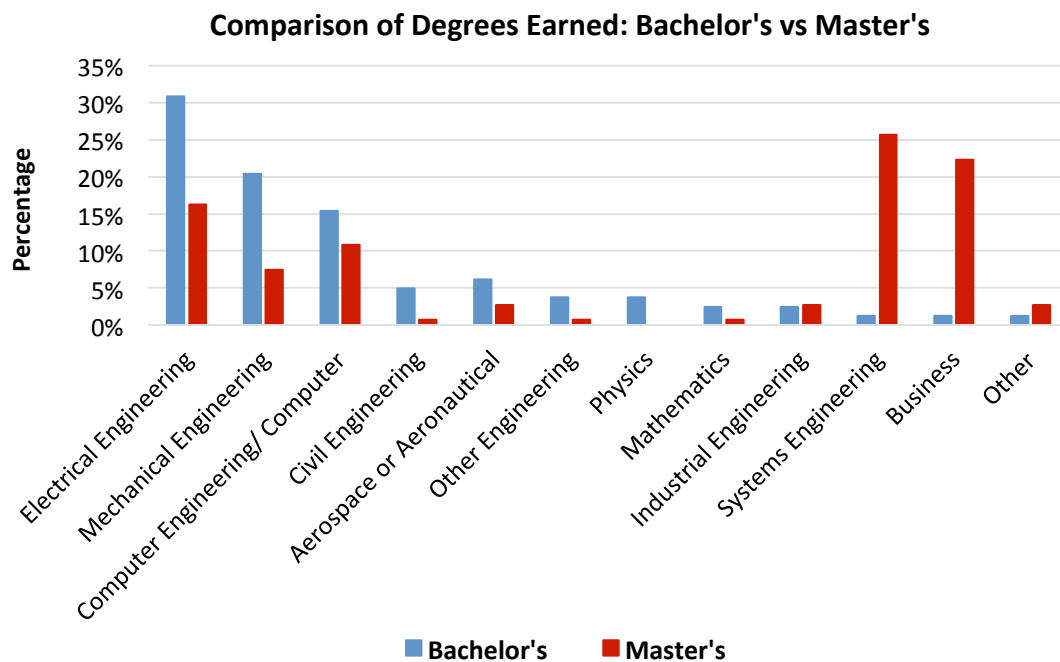


Figure 8. Comparison of degrees and majors achieved in Helix dataset

To provide context, Figure 9 provides a heat map of the Education data examined by the Helix team in the INCOSE SEP applicant dataset. In the figure red represents the lowest incidence of degrees awarded for a major, while great represents the highest. This includes all applicants for any SEP level, so would cover all levels of seniority. Of note is that electrical engineering, mechanical engineering, and computer sciences are the three most common bachelor’s degree majors – in that order – among the SEP applicants as well. This gives the Helix team confidence that this is not anomalous to the Helix dataset.

| 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       |

Figure 9. Trends in bachelor’s degree majors among INCOSE SEP applicants.

Next, to identify similarities and differences among systems engineers, it is necessary to decompose the most frequent bachelor’s degrees by seniority level. Figure 10 shows that the electrical engineering major is the most popular major among all the systems engineers. A small difference is reflected at the second most popular major. Junior and Senior systems engineers have Mechanical Engineering as a preferred undergraduate major, while Mid-Level systems engineers typically hold computer-related majors.

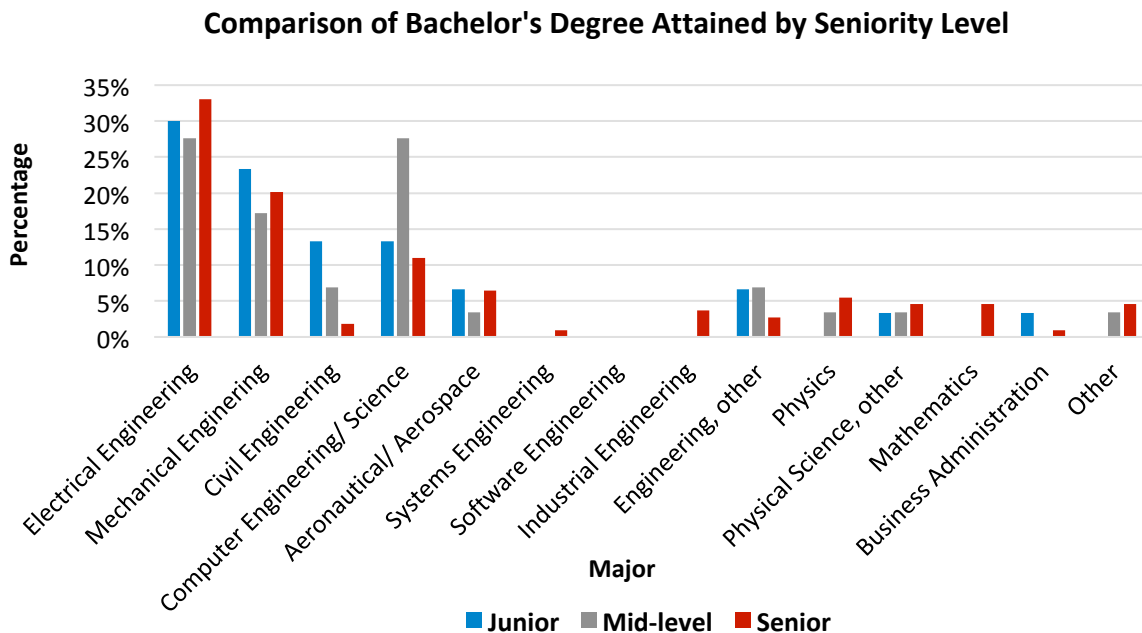


Figure 10. Comparison of bachelor's degrees attained by interviewed systems engineers

In the 2000-2010 time frame, when most junior systems engineers in the Helix dataset were attaining their education, electrical, mechanical, and civil engineering were the three most common majors in all engineering degrees in the US, although their ranking changed a bit during the decade, as shown in Figure 11. (NCES 2011) The percentages for junior systems engineers generally align with the overall US attainment of these degrees during this time period.

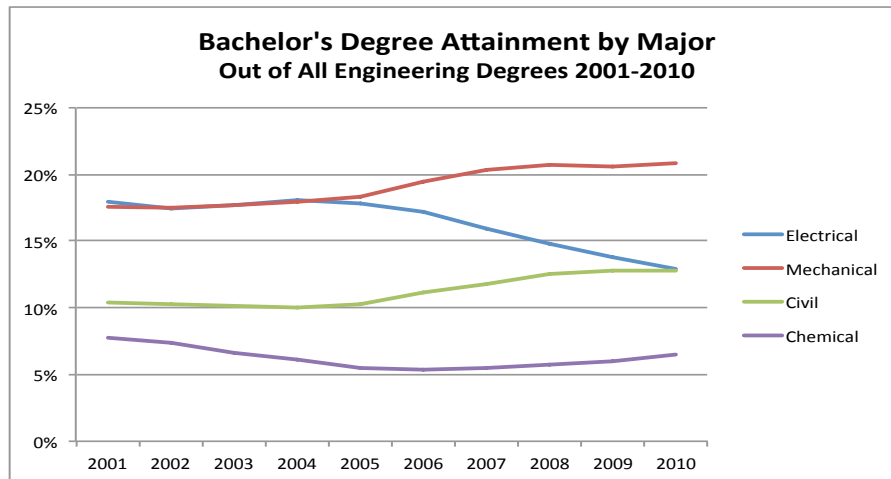


Figure 11. Comparison of most popular bachelor's engineering majors in the US from 2001-2010. (NCES 2010)

A more significant variation is seen at the master's degree level. The most popular major for master's degree is Systems Engineering for Junior and Mid-level engineers. On the other hand, data reflects that Senior systems engineers chose Electrical Engineering and Business Administration as preferred graduate level majors. Figure 12 shows the distribution of selected master's degrees. Junior and mid-level engineers adopted Systems Engineering as a preferred major while Senior engineers chose more traditional degrees. Senior systems engineers in the dataset explained that they believed they had sufficient technical skills, but wanted to understand the business case for their engineering work and were, therefore more likely to pursue an MBA. Junior systems engineers, on the other hand, were more likely to pursue a degree in systems engineering. Again, they believed their general engineering skills were sufficient, but that they needed to learn more about systems engineering as a discipline.

### Comparison of Master's Degrees Attained by Seniority Level

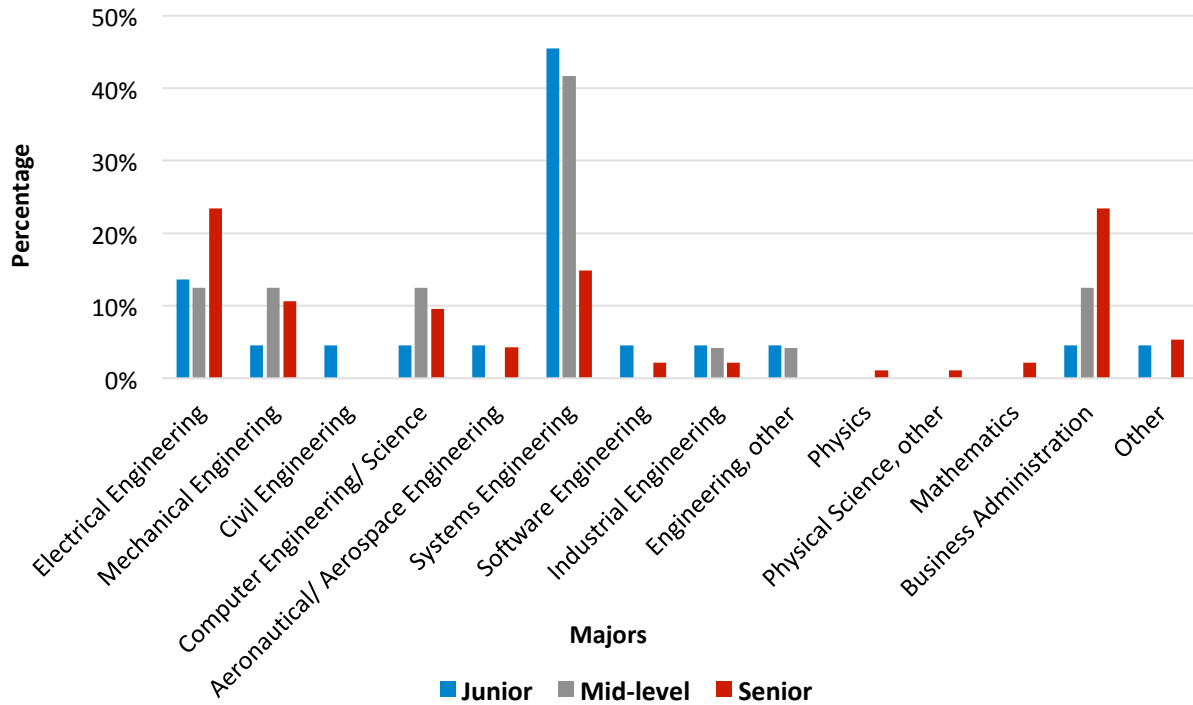


Figure 12. Comparison of master's degrees attained by interviewed systems engineers

Again it is useful to compare the Helix interview dataset to the INCOSE SEP dataset. The trend in increased systems engineering master’s education in recent years certainly matches the Helix patterns. Interestingly, MBAs are less common in the INCOSE SEP dataset, though this data also shows a growth trend over time.

| 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       |

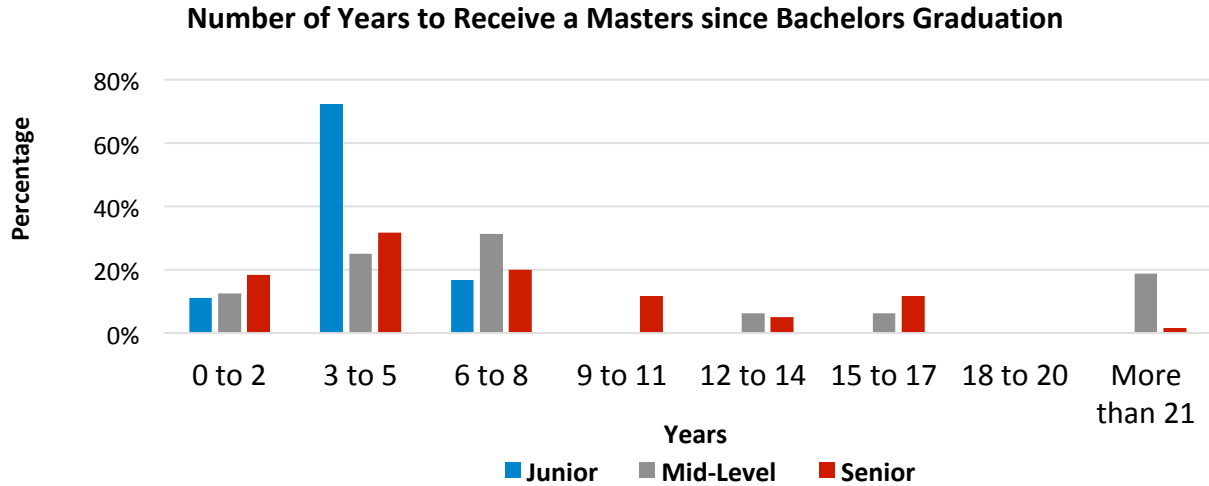
Figure 13. Trends in master’s degree majors among INCOSE SEP applicants

There is a steady growth trend in systems engineering graduate education in the US (Lasfer and Pyster 2013). As the availability of systems engineering graduate education increases, it is reasonable that an increased number of junior systems engineers would seek a master’s in the field. This cannot, however, account for the fact that over half of masters degrees awarded to junior systems engineers were systems engineering. Junior systems engineers explained that they sought graduate degrees in the field for multiple reasons:



- *To learn other ways of doing things.* Junior systems engineers often have worked in only one or two organizations. Where they see limitations in the way systems engineering is done in these organizations, they often feel powerless to make changes. By studying systems engineering academically, however, they believe they can better understand alternatives and have a better chance of making an impact on their organization.
- *Broadening of knowledge.* Junior systems engineers almost unanimously expressed a desire to see different parts of the lifecycle, experience different technologies, understand new techniques in the field, etc. However, these experiences are not always possible in their current organizations or may not be available as soon as the junior systems engineers desire. By obtaining a master's degree in systems engineering, junior systems engineers can at least gain more knowledge on the aspects of systems engineering they have not yet experienced, understand lifecycles from a more holistic perspective, understand multiple processes, and gain exposure to different types of tools. While all of the junior systems engineers who have graduate degrees in systems engineering indicated that they learned a substantial amount in their programs and are happy that they chose to pursue a master's degree in the field, they also almost unanimously expressed concern that their knowledge and skills will atrophy if they are not able to practice them.
- *General career growth.* Junior systems engineers generally expressed a desire for growth in their careers and believed that earning a master's degree in the discipline would help with this in several ways. First, simply obtaining graduate level education in some cases made them eligible for promotions or other incentives that they otherwise would not have had. Second, systems engineers are often in the position of having to influence engineering decisions without having authority over the engineers doing the work or making the decisions. Several junior systems engineers stated that having a master's degree gave them at least some level of "street credit". It should be noted, however, that desire for growth in knowledge and skills was also discussed before career growth – if career growth was discussed at all – and always to a greater depth.

In terms of the timing of graduate education, systems engineers on average pursue a graduate degree in less than eight years after bachelor's graduation. As it can be seen in Figure 14, more than 70% of junior engineers from the dataset examined received a graduate degree in the following 3 to 5 years after obtaining a bachelor's degree.



**Figure 14. Comparison of number of years to receive a Master's degree**

Also, Figure 14 shows a more spread distribution for mid-level and senior engineers. Over half of mid-level and senior systems engineers obtained their masters degrees between 3 and 8 years after completing their graduate degrees. In general, junior systems engineers in the sample reported being encouraged to pursue a master's degree soon after joining their organizations. Many of the organizations also had cohorts of systems engineers go through master's degree programs, which again explains the earlier timing of graduate education and the emphasis on systems engineering among junior systems engineers.

Another aspect the Helix team considered in the career path analysis was the experiences in systems engineering. Next sections discuss systems engineering experiences in terms of lifecycle, roles, system type, system scope, and keyword and cluster analysis.

In terms of doctoral education, 8% of the individuals in the Helix dataset held a PhD. The areas of study for these degrees is shown in Figure 15.

**Table 4 Doctoral areas of study in Helix dataset**

| Major                                    | Percentage |
|--|------------|
| Systems Engineering                      | 31%        |
| Mechanical Engineering                   | 19%        |
| Electrical Engineering                   | 13%        |
| Technology Management                    | 6%         |
| Atmospheric, Oceanic, and Space Sciences | 6%         |
| Geotechnical Engineering                 | 6%         |
| Psychology                               | 13%        |
| Anthropology                             | 6%         |

In the INCOSE SEP dataset, of the 200 applicants who held a PhD or equivalent degree (Juris Doctor, Doctor of Science, etc.) nearly half had studied either electrical or systems engineering, as illustrated in Figure 15.

| Engineering Major                         | %   |
|---|-----|
| Electrical Engineering                    | 25% |
| Systems Engineering                       | 23% |
| Aeronautical or Astronautical Engineering | 13% |
| Mechanical Engineering                    | 8%  |
| Biomedical Engineering                    | 5%  |
| General Engineering                       | 6%  |
| Other Engineering                         | 19% |

**Figure 15. Doctoral Areas of Study in INCOSE SEP Dataset**

The comparison of the doctoral degrees awarded shows that, systems engineering is the second most common PhD field of study in both datasets.

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## **3.2. EXPERIENCES**

Position patterns are those related to individuals performing systems engineering activities within their roles and responsibilities. Position is considered as the unit of measure for experience since time is not easily identified in the data collected. For instance, a participant may have described a position held over a ten-year period, during which he performed multiple systems engineering activities and focused on different system levels, but did not necessarily described the time spent performing the different activities. Therefore, due to those limitations in the data available, position was considered as the standard unit of measure for experience.

Experiences in systems engineering are categorized in the following: lifecycle, roles, system type, system scope, and keyword and cluster analysis.

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### **3.2.1. EXPERIENCES ACROSS THE SYSTEMS ENGINEERING LIFECYCLE**

This section aims to depict the contrast between junior, mid-Level, and senior systems engineers with respect to their experience with lifecycle phases. Table 5 describes the five lifecycle phases considered based on the *Guide to the Systems Engineering Body of Knowledge* (SEBoK) and the orthogonal “Systems Engineering Management.” (BKCASE Authors, 2015)

**Table 5. Definition on lifecycle phases according to SEBoK (BKCASE Authors, 2015)**

| Lifecycle Phase                     | Definition   |
|-------------------------------------|--|
| Concept Definition                  | A set of core technical activities of SE in which the problem space and the needs of the stakeholders are closely examined. This consists of analysis of the problem space, business or mission analysis, and the definition of stakeholder needs for required services within it.   |
| System Definition                   | A set of core technical activities of SE, including the activities that are completed primarily in the front-end portion of the system design. This consists of the definition of system requirements, the design of one or more logical and physical architectures, and analysis and selection between possible solution options.   |
| System Realization                  | The activities required to build a system, integrate disparate system elements, and ensure that a system both meets the needs of stakeholders and aligns with the requirements identified in the system definition stage. This includes integration, verification, and validation (IV&V)   |
| System Deployment and Use           | A set of core technical activities of SE to ensure that the developed system is operationally acceptable and that the responsibility for the effective, efficient, and safe operations of the system is transferred to the owner. Considerations for deployment and use must be included throughout the system life cycle. Activities within this stage include deployment, operation, maintenance, and logistics  |
| Product and Service Life Management | Deals with the overall life cycle planning and support of a system. The life of a product or service spans a considerably longer period of time than the time required to design and develop the system. This stage includes service life extension, updates, upgrades, and modernization, and disposal and retirement. The organizations in the current sample are primarily concentrated on new development, so this is a very under-represented aspect of the life cycle. |
| Systems Engineering Management      | Managing the resources and assets allocated to perform SE activities. Activities include planning, assessment and control, risk management, measurement, decision management, configuration management, information management, and quality management. These activities can occur at any point in the systems engineering lifecycle.  |

To map the systems engineering lifecycle stages, the team first identified every single relevant position for each systems engineer. Then, a description of the activities performed at each position supported the Helix team when identifying the lifecycle stages the engineer participated in. The categorization was then clustered into junior, mid-level, and senior systems engineer.

Figure 16 denotes the distribution of lifecycle stages by position for **junior** systems engineers. Note that not all junior systems engineers have had five positions yet in their careers; the percentages are the percent of junior systems engineers who reporting having that position. Junior systems engineers have focused primarily on System Definition over their careers. System Realization is the second most observed stage for the first four positions, then at

position 5, junior engineers transition to Systems Engineering Management. Note that not all junior systems engineers in the sample have five positions.

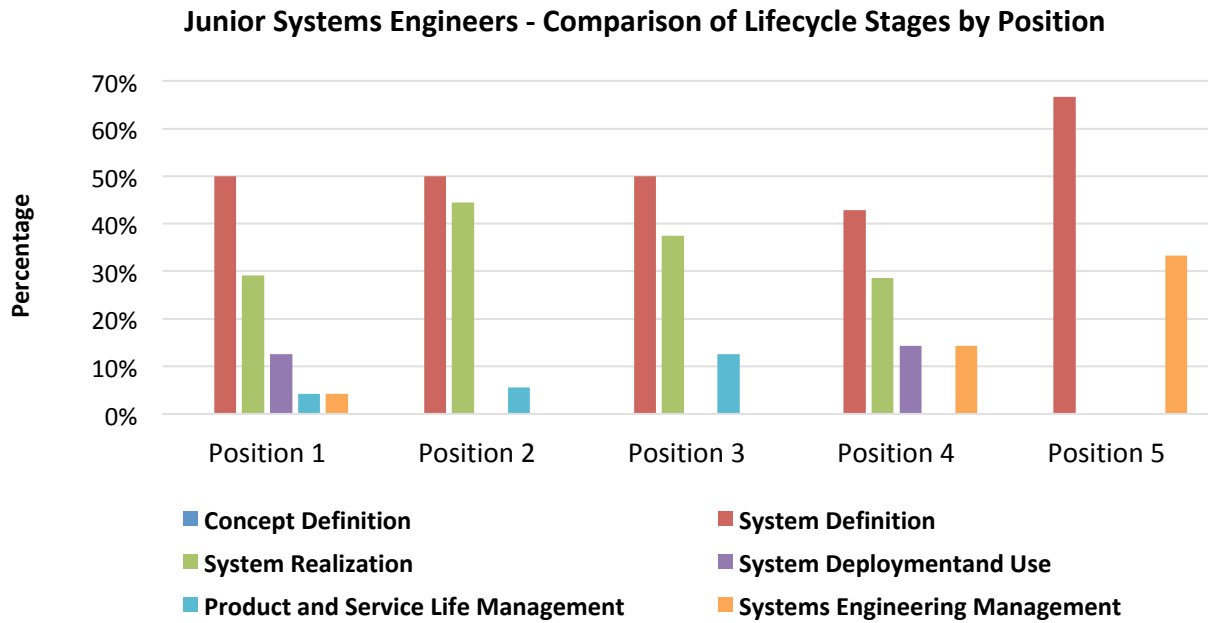


Figure 16. Comparison of lifecycle stages across junior systems engineers

Mid-Level systems engineers experienced more variety in first five positions compared to junior systems engineers. Figure 17 reflects that mid-Level slightly more mid-level systems engineers in the sample started in System Realization, often performing testing or other V&V related functions, than junior systems engineers. In positions 3-4, System Definition is the most common lifecycle phase experienced, but again nearly the same number of mid-level systems engineers experienced System Realization in these positions. In position 5, most mid-level systems engineers reported transitioning to leadership or management roles. As it can be seen, by position 5 more than 30% of mid-level engineers are involved in the Systems Engineering and Management stage. This aligns with the small number of junior systems engineers in the sample who have reached position 5 and also have become more engaged with Systems Engineering Management.

### Mid-Level Systems Engineers- Comparison of Lifecycle Stages by Position

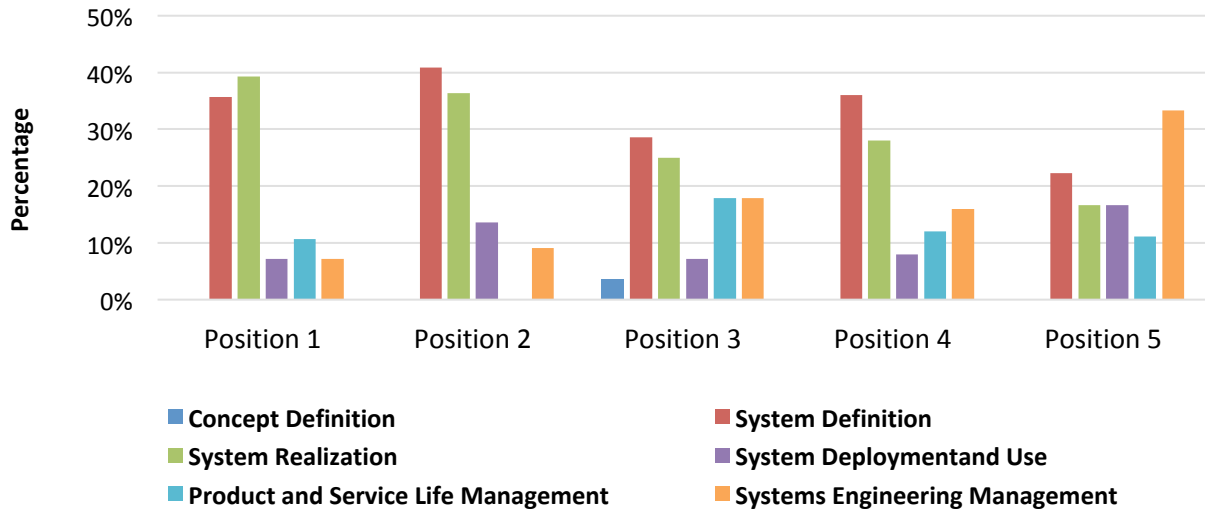


Figure 17. Comparison of lifecycle stages across mid-level systems engineers

This pattern – of significant increases in Systems Engineering Management – repeats for senior systems engineers, as shown in Figure 18. In a similar trend with respect to junior and mid-level systems engineers, senior engineers focus on the first four positions in System Definition and System Realization stages. Also, position 1 for senior and mid-level engineers reflects that both seniority levels were slightly more likely to start their career at System Realization, in contrast to junior engineers who were more likely to begin at System Definition. Lastly, Systems Engineering and Management is the most frequent stage starting at position 5 and position 6. This is due to the fact that senior engineers take over leadership or management roles.

### Senior Systems Engineers - Comparison of Lifecycle Stages by Position

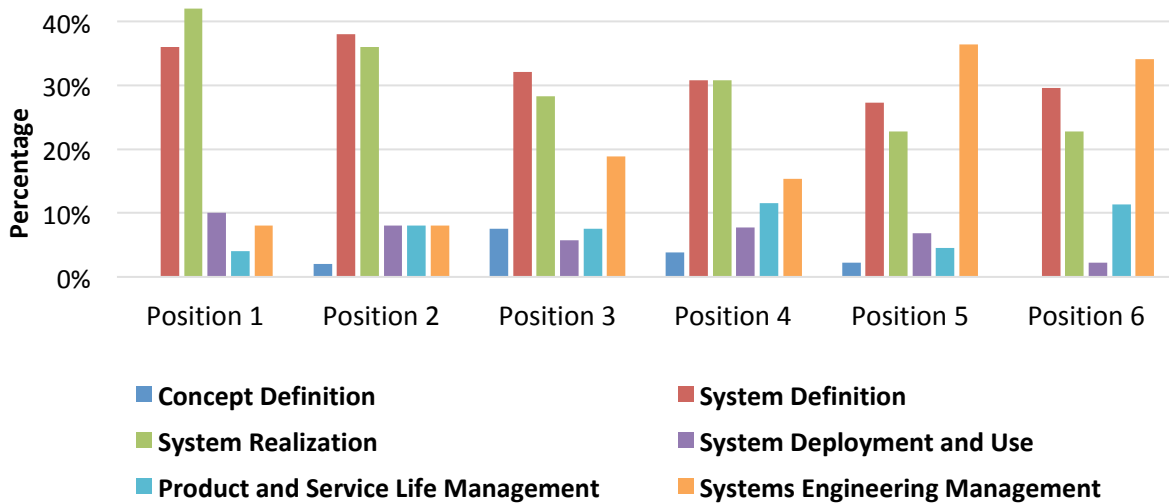


Figure 18. Comparison of lifecycle stages across senior systems engineers

### Interpreting the Results

What does this view of lifecycle stages mean? The first is that there is no one single way to move through the systems engineering lifecycle. There are a clear patterns – overall System Definition and System Realization are common lifecycle phases across all positions and around position 5, a systems engineer would be expected to start engaging in systems engineering management. However, when the Helix team tried to map all of the different paths through the phases of the lifecycle, they discovered 78 distinct paths! In fact, no single path was followed by more than 6% of the sample and this 6% were junior systems engineers with only two lifecycle stages in their career paths – meaning they could still diverge. Therefore, the patterns highlighted above actually provide more insight than a single, particular career path. Some key items to note:

- None of the systems engineers in the sample have experience in only one aspect of the life cycle. It was stated repeatedly in both initial and follow up interviews that it is critical that systems engineers understand multiple stages of the life cycle. This data seems to confirm the general belief that an individual who has experienced only one stage of the life cycle is likely not ready to be a systems engineer. It also aligns with the Helix seniority framework, which identifies an individual as a junior systems engineer only if they have experience in at least two lifecycle stages.
- Around 9% of the individuals in the current sample have experience in all lifecycle stages plus systems engineering management. In the current organizational sample, most organizations were not heavily involved in modernization or disposal efforts, limiting the

number of individuals who have the possibility of experiencing “Produce and Service Life Management.” About 17% have experiences in 5 stages.

- The majority (about 77%) of the senior systems engineers in the current analysis have experience in four or more stages of the life cycle. This aligns with the assumption that senior systems engineers develop in part by exposure across the life cycle. Again, this is primarily from industry as most government resumes did not include this level of detail. This is one of the criteria for a senior systems engineer. The other senior systems engineers tended to be younger, so had seen fewer lifecycles but held many leadership positions, worked at the system levels, and played many roles (fulfilling all but the lifecycle guidance to be classified as “senior”).

There are plenty of opinions on “the right” way through the lifecycle – in fact, in the Helix dataset, there were two very strong recommendations for senior systems engineers: start at the beginning of the lifecycle and work through the entire cycle until the end or start at the end and work through the entire cycle through to the beginning. In fact, only one individual went through the lifecycle from Concept Definition through to Product and Service Life Management in order (and even that individual focused on Systems Engineering Management before getting to Product and Service Life Management). There was no one in the sample that had been through the entire lifecycle backwards and very few started with “Product and Service Life Management”.

There are some challenges to both of these approaches – namely that, particularly in traditional defense programs, lifecycles tend to be long and the amount of time it would take to see a lifecycle through to completion on a program can be several years. Many senior systems engineers recommended going through the lifecycle on a single program – but again, with some programs lasting 20 years or longer, this is a difficult development path. Working backwards through the lifecycle has the same problems – and the added difficulty of having to learn a new program with each move. Even outside of defense, this can be difficult. For example, the average time from concept generation to fielding a system in the FAA is seven years. In some commercial sectors, program times may be shorter, making this sort of holistic approach more feasible.

However, as discussed above there are many successful systems engineers who did not take either of these paths through the lifecycle. When the Helix team asked individuals to describe the rationale behind their recommendations in interviews, and interestingly – and perhaps not surprisingly – most recommended a path similar to the one they had taken. Several went on to explain, however, that it was less the *order* in which the individuals experienced the lifecycle and more the ability to take learning from one area and apply it to another. There were many examples of this, but a few are included here: discovering design problems rooted in allocation of requirements in testing and taking that knowledge into their eventual design work to avoid those same problems; identifying gaps in the understanding of an engineering team and the end user as operators or maintainers and bringing that perspective into design or testing to ensure better alignment; failing a validation test and realizing that lack of understanding of the customer needs was the primary problem; having to test one’s own designs and realizing the



flaws in them. All of these anecdotes illustrated a pattern that highlighted one of the *Atlas* proficiencies: abstraction, the ability to filter out and understand the critical bits of information at the right level and to make relevant inferences. It also helps them to be able to identify patterns and apply them in different contexts.

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### 3.2.2. ROLES

A position held by an individual is equivalent to a 'title', where the organization defines what roles and responsibilities it entails. Each position has a variety of characteristics, which align with the characteristics of experiences including the length of the position, the types of systems worked on in that position, the roles played, and the aspects of the lifecycle seen.

An individual systems engineer fills a position (or holds a title) in an organization, and there are many roles that the systems engineer is expected to perform in that position. *Atlas* identifies 15 systems engineering roles; typically, a systems engineer performs a combination of these roles while holding a single position. Starting with the 'twelve systems engineering roles' identified by Sheard (1996). The Helix team recombined, renamed, removed, and added roles to reflect the Helix data collected during interviews about the activities systems engineers perform in organizations today. This was socialized with the community through conference papers and presentations, the Helix workshops, and through early adopter activities with several organizations.

Table 6 highlights the clustering of roles suggested by the Helix team in three categories:

- **Roles Focused on the System Being Developed.** These roles are what may most quickly come to mind when describing a systems engineer. They are roles that align closely with the systems engineering lifecycle and the critical activities systems engineers must enable throughout the lifecycle.
- **Roles Focused on SE Process and Organization.** These roles focus on the organizational context in which systems engineering occurs and the critical role of systems engineers in providing guidance on how systems engineering should be utilized.
- **Roles Focused on Teams That Build Systems.** Systems engineering does not occur in a vacuum; it is, instead, an intensely social discipline. The roles in this category are those that focus on enabling diverse, multi-disciplinary teams to be successful.

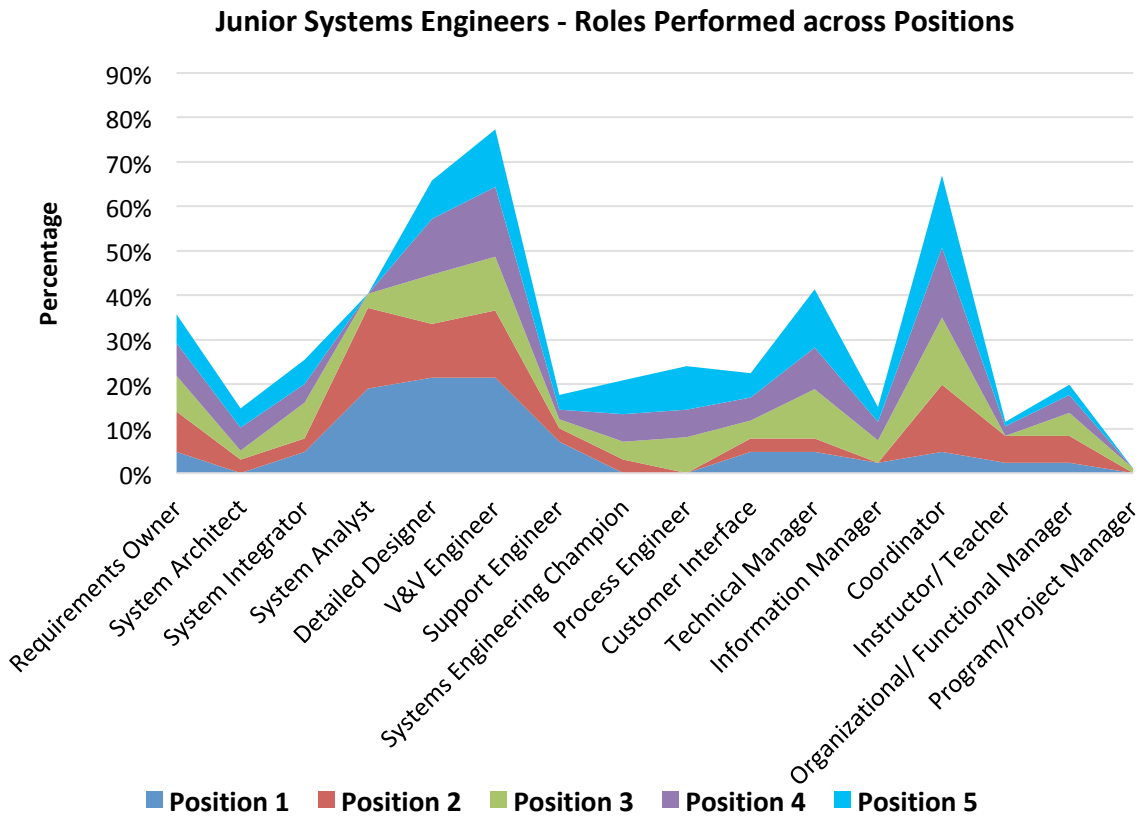
Table 6. Description of systems engineering roles identified by Helix

| Role Name                                     | Role Description   |
|---|--|
| <b>Focused on the Systems Being Developed</b> |  |
| <b>Concept Creator</b>                        | Individual who holistically explores the problem or opportunity space and develops the overarching vision for a system(s) that can address this space.   |
| <b>Requirements Owner</b>                     | Individual who is responsible for translating customer requirements to system or sub-system requirements.  |
| <b>System Architect</b>                       | Individual who owns or is responsible for the architectures of the system; this including functional and physical architectures.   |
| <b>System Integrator</b>                      | Individual who provides a holistic perspective of the system; this may be the ‘technical conscience’ or ‘seeker of issues that fall in the cracks’ – particularly, someone who is concerned with interfaces.   |
| <b>System Analyst</b>                         | Individual who provides modeling or analysis support to system development activities, and helps to ensure that the system as designed meets the specification.  |
| <b>Detailed Designer</b>                      | 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.  |
| <b>V&amp;V Engineer</b>                       | Individual who plans, conducts, or oversees verification and validation activities such as testing, demonstration, and simulation.   |
| <b>Support Engineer</b>                       | Individual who performs the ‘back end’ of the systems lifecycle, who may operate the system, provide support during operation, provide guidance on maintenance, or help with disposal.   |
| <b>Focus on Process &amp; Organization</b>    |  |
| <b>Systems Engineering Champion</b>           | Individual who promotes the value of systems engineering to individuals outside of the SE community - to project managers, other engineers, or management.   |
| <b>Process Engineer</b>                       | Individual who defines and maintains the systems engineering processes as a whole and who also likely has direct ties into the business. This individual provides critical guidance on how systems engineering should be conducted within an organization context. |
| <b>Focus on Teams That Build Systems</b>      |  |
| <b>Customer Interface</b>                     | Individual who coordinates with the customer, particularly for ensuring that the customer understands critical technical detail and that a customer’s desires are, in turn, communicated to the technical team.  |
| <b>Technical Manager</b>                      | Individual who controls cost, schedule, and resources for the <i>technical</i> aspects of a system; often someone who works in coordination with an overall project or program manager.  |
| <b>Information Manager</b>                    | Individual who is responsible for the flow of information during system development activities. This includes the systems management activities of   |

| Role Name                      | Role Description   |
|--------------------------------|--|
|                                | configuration management, data management, or metrics.   |
| <b>Coordinator</b>             | Individual who brings together and brings to agreement a broad set of individuals or groups who help to resolve systems related issues. This is a critical aspect of the management of teams.  |
| <b>Instructor/<br/>Teacher</b> | Individual who is provides or oversees critical instruction on the systems engineering discipline, practices, processes, etc. This can include the development or delivery of training curriculum as well as academic instruction of formal university courses related to systems engineering. |

Following the above definitions, the team identified the roles performed, in chronological order, by systems engineers at each position. Then, job descriptions and interviews were utilized to capture the pertinent roles systems engineers executed at each position. Results were then evaluated and compared among the multiple seniority levels.

Figure 19 illustrates the roles performed by junior systems engineers. It is noted that at position 1 the most frequently performed roles are Detailed Designer and V&V Engineer. After position 3, another major shift occurs. Junior engineers transitioned from tasks related to analyzing the system to activities necessary to coordinate a set of individuals. Overall, in their first five positions, junior systems engineers are more likely to play the roles of System Analyst, Detailed Designer, V&V Engineer, or Coordinator. Note that the coordinator role for junior systems engineers often worked in one of two ways: the individual was coordinating a small team on a small project or component or the individual was supporting a senior systems engineer and one of their roles was to help with team coordination.



**Figure 19. Roles performed by junior systems engineers**

The roles performed by mid-Level systems engineers are slightly different at the beginning of their careers compared to junior engineers; however they seem to converge similarly as their career progresses. Mid-level systems engineers seemed to have started their career performing verification & validation activities for the first two positions, which aligns with junior systems engineers. However, after position 3, mid-level systems engineers performed the role of Coordinator more frequently. Figure 20 illustrates the evolution of roles performed by Mid-Level systems engineers.

### Mid-Level Systems Engineers - Roles Performed across Positions

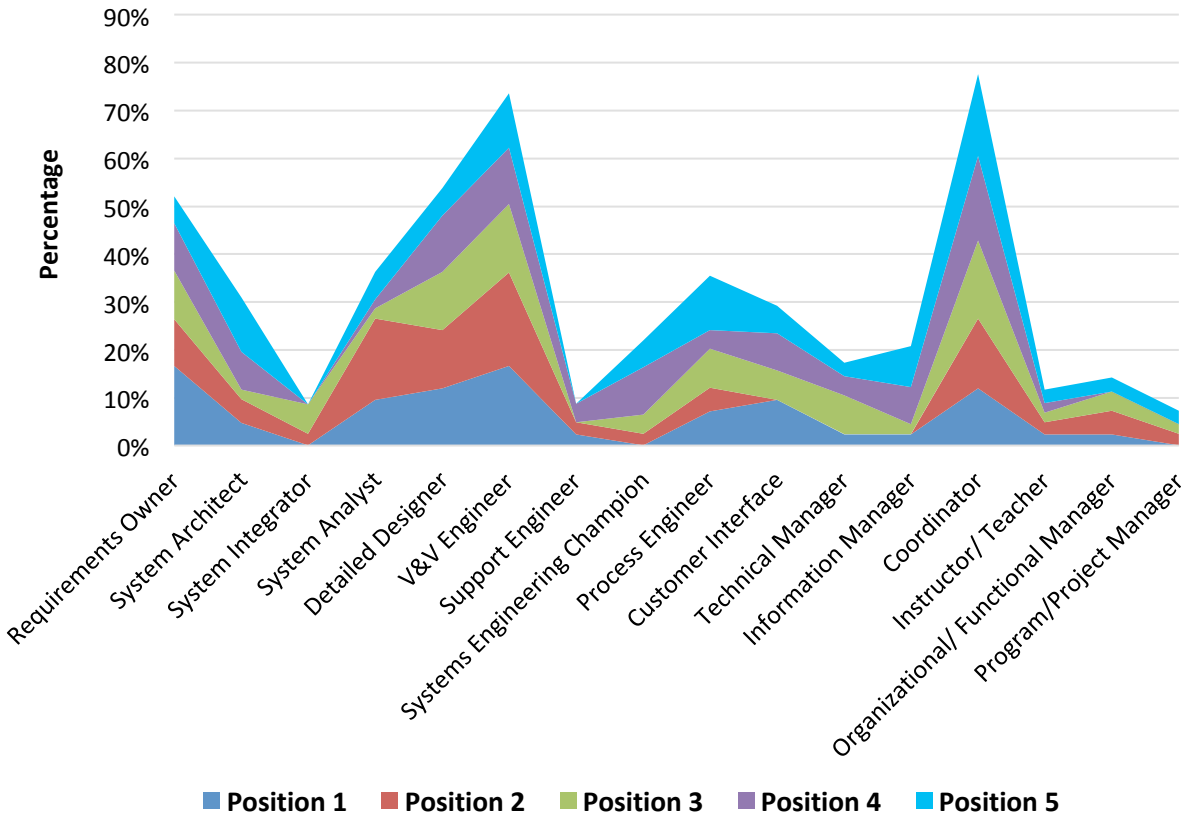


Figure 20. Roles performed by mid-level systems engineers

Figure 21 shows the path followed by Senior systems engineers in regard to the roles performed across positions. Senior systems engineers followed a similar distribution as the Junior and Mid-Level systems engineers. Position 1 and position 2 are characterized by performing Verification & Validation roles. Then, Position 3, position 4 and position 5 converge at Coordination roles. A remarkable note is the increase and convergence after position 3 to Technical Manager role. It is expected that systems engineers acquire more technical and management responsibilities since their third position.

### Senior Systems Engineers - Roles Performed across Positions

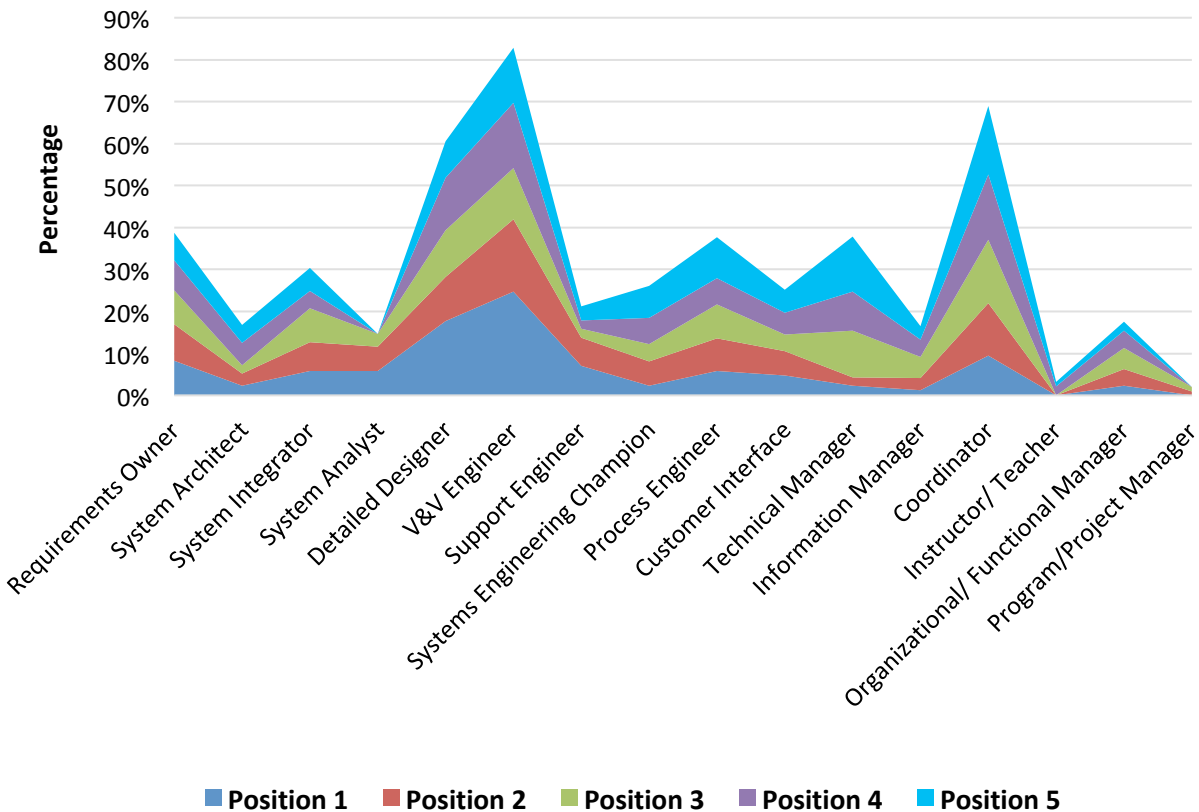


Figure 21. Roles performed by senior systems engineers

### Interpreting the Results

There are several patterns around the roles of systems engineers that can help guide individuals in their career choices.

The most common role played in position 1 across seniority levels was V&V engineer. In almost all cases, these individuals started as testers trying to verify that system requirements had been met through a variety of techniques, often finding faults and having to trace those faults back to the root cause. Many of them reported that the root cause was often a failure of requirements or of integration between the engineering teams – and thus their designs. Individuals who started as V&V Engineers reported that this role helped them to be better prepared to become effective Detailed Designers and System Architects. Interestingly, junior and mid-level systems engineers were more likely to move from V&V Engineer into Systems Analyst than their senior counterparts, who were more likely to continue as V&V Engineers in their second positions.

Another common early role is Detailed Designer. This is unsurprising because it was common for an individual to work as a specialty engineer performing some design functions at a lower level before becoming a systems engineer.

Several senior interviewees stated that junior systems engineers often take on roles that cover only a small part of the life cycle, often a role in testing or requirements. Interestingly, though, it was more likely that a mid-level systems engineers would be a Requirements Owner in their first position than for a junior systems engineer. Because in general a mid-level systems engineer’s first position was chronologically early than a junior systems engineer’s, it is possible that this reflects a change over time in the roles that junior systems engineers are expected to play.

In regards to leadership and management, the analysis indicates that systems engineers started to perform leadership and management positions at their third position. For instance, it was observed that the words: manager, lead, director and chief were in the title of the positions occupied. This pattern has been consistent across the junior, mid-level and senior systems engineers.

Roles such as Customer Interface or Process Engineer by nature require more experienced systems engineers. In both initial and follow up interviews, several senior systems engineers stated that it was critical that customer interactions be done by more senior individuals who not only have a grasp of the technology but who have honed their communication skills – primarily their ability to translate technical data for non-technical audiences and vice versa. Several of these individuals stated that a less experienced systems engineer simply does not have the ability to do this effectively. Likewise, senior engineers who spoke of performing process engineering tasks explained that it required that the individual had applied the process in a variety of contexts and see where it was both successfully and unsuccessfully implemented. It seems unlikely that junior systems engineers would have this breadth of experiences to support their ability to perform process engineering.

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### 3.2.3. SYSTEM TYPE

System type is refers to the nature of the system of interest. The Helix team classifies system types into: product, service and enterprise. The objective is to identify similarities and differences in the type of systems junior, mid-Level and senior systems engineers are exposed to. Table 6 reflects the definition for each system typed identified by Helix team.

**Table 7. System type definition implemented by the Helix team**

| Type    | Definition   |
|---------|--|
| Product | A system considered from the point of view of a physical “system end product” made of system elements that may include hardware, software, infrastructure and support services. The people and organizational aspects of |

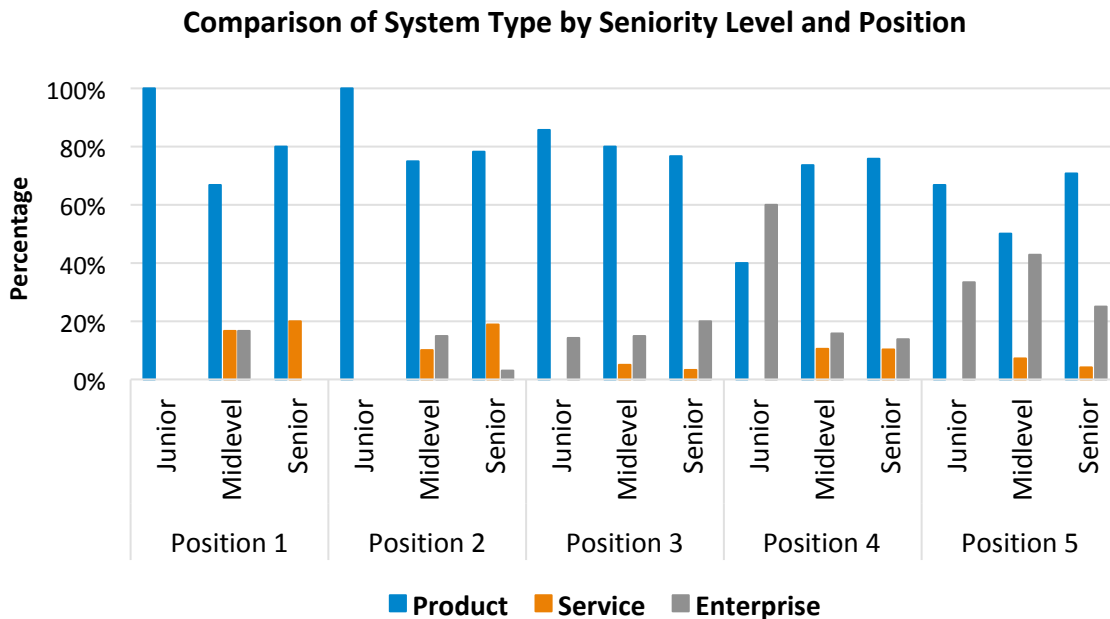
|            |   |
|------------|---|
|            | the “whole system” of which the “product system” forms a part have to be considered in the design, but are provided by another organization.  |
| Service    | A dynamic configuration of resources (people, technology, organizations and shared information) that creates and delivers value between the provider and the customer through services.   |
| Enterprise | A complex, (adaptive) socio-technical system that comprises interdependent resources of people, processes, information, and technology that must interact with each other and their environment in support of a common mission to offer an output such as a product or service. |

Following the definitions of Table 5, the team identified the roles performed, in chronological order, by systems engineers at each position. Then, job descriptions and interviews were utilized to capture the pertinent system types systems engineers were involved to. Results were then evaluated and compared among the multiple seniority levels.

Figure 22 shows a comparison between seniority level and system type. It is interesting that 100% of junior systems engineers started their career by focusing on product systems in both their first and second positions. While the majority of mid-level and senior systems engineers also started working on product systems, a small number did work on services or enterprises. This could reflect the participating organizations, which were mainly product-focused.

Junior systems engineers eventually transitioned to service and enterprise-type of systems. Mid-Level and senior engineers seemed to have more diversity in regard to system types. Senior engineers seemed to start their career focusing on product and occasionally service systems, but as their careers progressed, small increments of enterprise systems occurred until more than 20% of them were focused at the enterprise level. This kind of growth in scope is not necessarily surprising, but it is interesting to note that, overall, product systems dominate and service or enterprise systems are less common. Again, this may represent bias in the Helix sample.





**Figure 22. Comparison of system type and seniority level**

**Interpreting the Results**

It is important not to over-interpret the results of the system type analysis. As stated above, it is possible that sampling bias is responsible for the heavy presence of product systems in the experiences of the systems engineers in the Helix sample. It is also possible that, in general, organizations which focus on product systems are more likely to think about systems engineering as a separate discipline and, therefore, participate in the study.

The only clear pattern here is that it is unlikely that a junior systems engineer will be asked to work on service or enterprise systems. As these are generally considered more complex than enterprise systems, this seems reasonable.

**3.2.4. SYSTEM SCOPE**

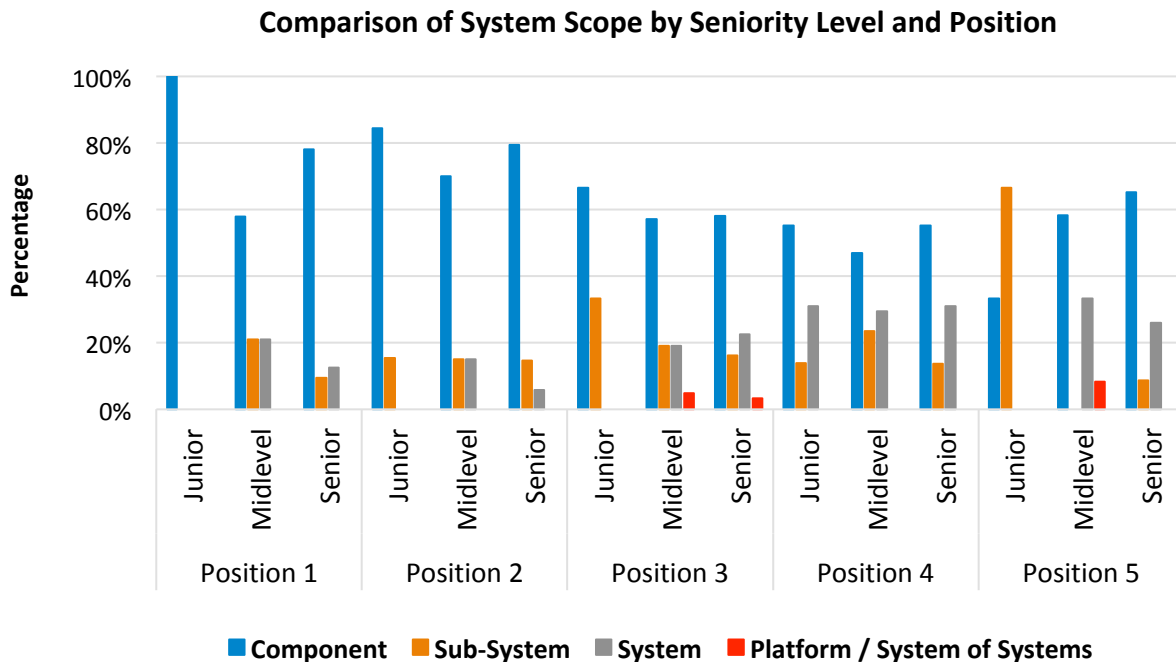
System scope defines level of abstraction where the systems engineers are performing their activities. Table 8 describes the system levels identified by Helix. These include component, sub-system, system and platform or system of systems.

To determine the level of exposure to a system by an individual’s systems engineer, the team first identified the positions in chronological order. Then, job descriptions and interviews were utilized to capture the pertinent system scope systems engineers were involved to. Results were then evaluated and compared among the multiple seniority levels.

**Table 8. Definition of system scope levels**

| Level                         | Definition   |
|-------------------------------|--|
| Component                     | An entity with discrete structure, such as an assembly or software module, within a system considered at a particular level of analysis. |
| Subsystem                     | A self-contained system within a larger system.  |
| System                        | A self-contained combination of interacting components organized to achieve one or more stated purposes.                                 |
| Platform / Systems of Systems | Two or more systems that are separately defined but together can perform a common goal.  |

Figure 23 illustrates that junior systems engineers commonly start their careers at the component level. As their careers advance, they are exposed to the sub-system or system level. Mid-level systems engineers show more diversity by starting at the component, sub-system and system level. Once they move up in their careers they get exposure to platform/system of systems. Most senior systems engineers started focusing at the component level but began working at the sub-system and system level. Through their career, Senior systems engineers have exposure to all system levels.



**Figure 23. Comparison of system scope and seniority level**

**Interpreting the Results**

Here the Helix data follows the patterns anticipated by the Helix team and described by almost all interviewees: systems engineers tend to start on small-scale areas, particularly in system

components, and their work grows in scope over time. It was uncommon for individuals to start working in a subsystem or system, but systems engineers tend to move up to the next level of system as they change positions. Many systems engineers described this as “the right way” to grow, stating that junior systems engineers need to grow build skills and a foundation of understanding at the component level and then expand that scope over time. However, there are examples of systems engineers who started their work at the subsystem or system level and reported that being able to “see the big picture” at this level was very helpful, even though they were new, and helped them become better integrators.

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### **3.2.5. KEYWORD AND CLUSTER ANALYSIS**

To visualize change in position titles, the Helix team resorted to Natural Language Processing techniques. First, position titles for each position and each seniority level were pasted in a new document. Then, a term frequency-inverse document frequency (tf-idf) method was utilized to obtain the most important term in the document (Salton and Buckley, 1988). Tf-idf has been utilized in information retrieval by selecting features in a collection of documents or corpus and analyzing the word frequency. The team implemented the tf-idf method to create wordclouds, a visualization method that correlates word frequency with word size. For this task, the team omitted the words “systems”, “engineering” and “engineer” due to the fact that they were the most frequent in each position. Since, the main goal is to discover patterns, by omitting the most frequent words, patterns emerged from the data.

Figure 24 illustrates the most frequent position titles for junior systems engineers by chronological position. It can be noted that at position 1, junior systems engineers performed apprenticeship technical position such as student intern and research assistant. At position 2 and on, systems engineers transition to technical position.

Only four positions are mapped for junior systems engineers as the majority of junior systems engineers have held four positions or fewer.

## Position Titles for Junior Systems Engineers



Figure 24. Most frequent position titles for junior systems engineers

Figure 25 depicts the most frequent position titles for mid-Level systems engineers by chronological position. Mid-Level engineers started their career in the technical area. Then, at position 3 is when more formal leadership positions are performed. It can be noted that some titles include the word “senior”, however they have not considered senior systems engineer since they do not meet the Helix criteria presented in Table 1. Also, due to the sample population of mid-Level engineers position 6 has low frequency of words, meaning only in few instances mid-Level systems engineers performed six positions.

## Position Titles for Mid-Level Systems Engineers

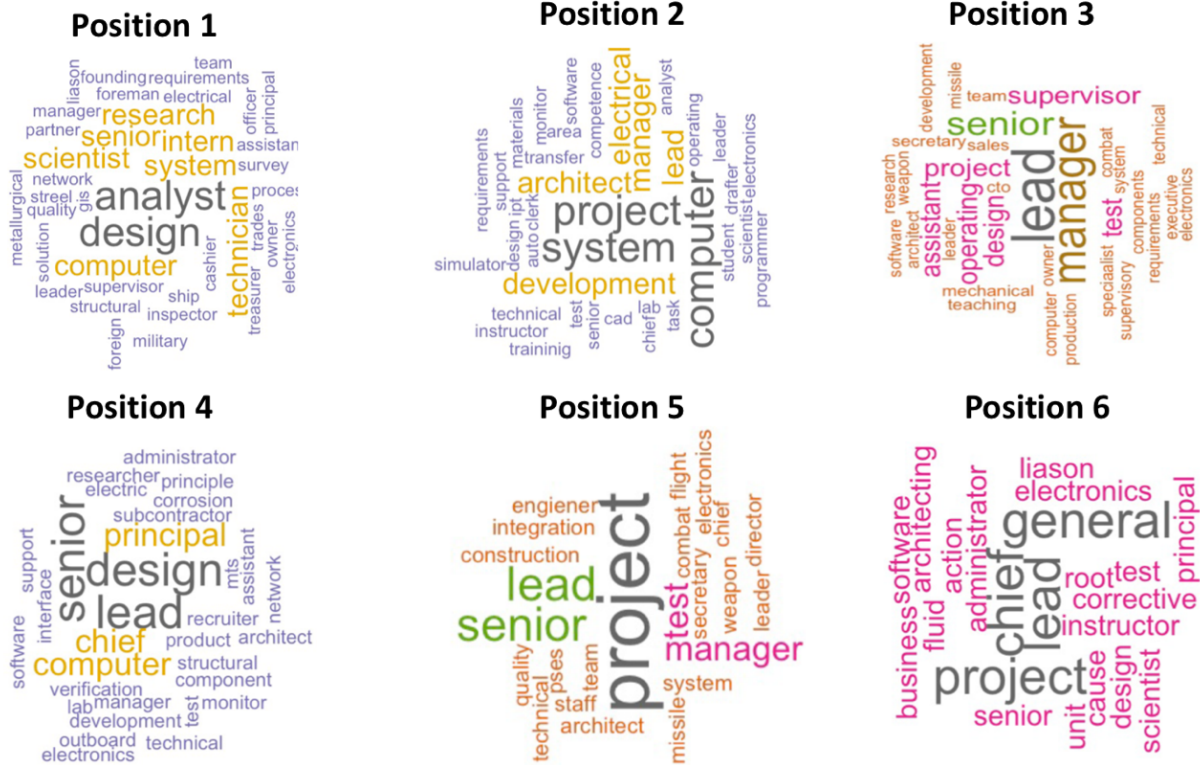


Figure 25. Most frequent position titles for mid-level systems engineers

Figure 26 illustrates the most frequent position titles for senior systems engineers. In a similar pattern to junior and mid-level engineers, senior systems engineers, play technical roles at their first position. Also, at position 3 the word “manager” gains significant weight. In contrast to other seniority levels, senior systems engineers start using the word “Chief” in their position titles at position 4. Then, it can be noted that senior engineers hold managerial and lead positions.

## Position Titles for Senior Systems Engineers



Figure 26. Most frequent position titles for senior systems engineers

Previous examples illustrate how text mining algorithms might be used to identify similarities in position titles for systems engineers. In broad terms, organizations recruit systems engineers for their technical skills as seen in the first position for junior, mid-level and senior systems engineers. Then, the third position is another benchmark for systems engineers when they acquire management responsibilities.

The next career pattern covers organizational career paths for systems engineers. It discusses the multiple fields where engineers have spent their careers and also the job mobility of junior, mid-level and senior systems engineers.

### 3.3. ORGANIZATIONS

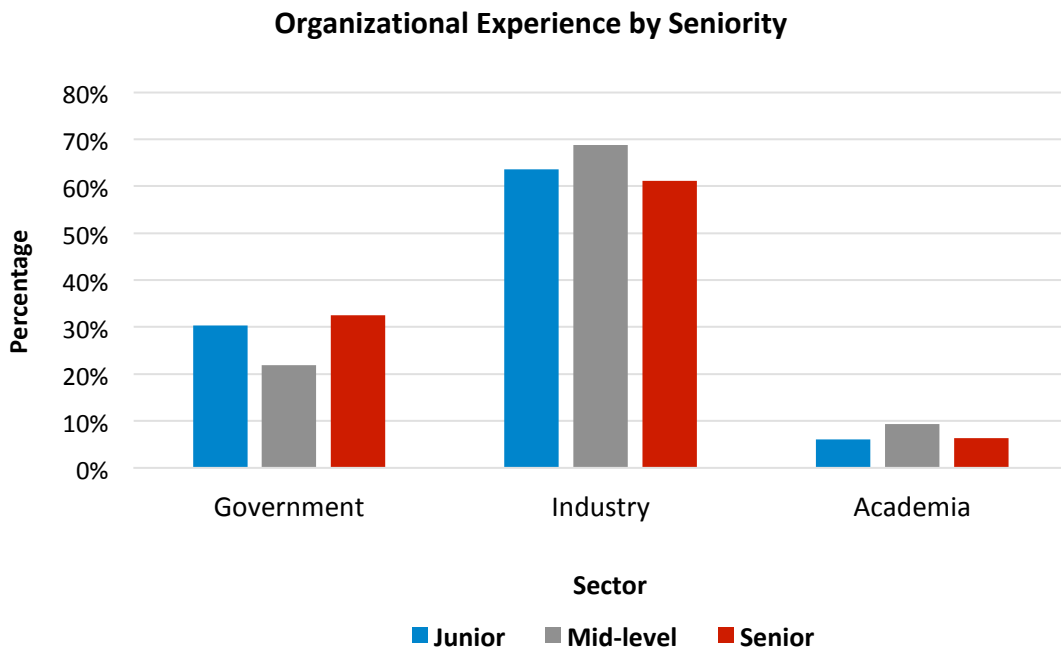
In terms of individual experiences, it is useful to understand the domain where a systems engineer has developed his skills. Helix classified organizations into government, industry, or academic organizations, or a combination of these.

In general, government systems engineers tend to oversee work done by systems engineers in industry as opposed to having the same direct responsibility for a system as seen in industry.

The different types of positions in the different sectors provide opportunities to develop new proficiencies – perhaps in new domains or operational contexts, or perhaps in new ways that systems engineering would be applied. However, some individuals stated that it might be difficult to transition between sectors because the overall ways in which the organizations operate, the processes used, and the cultures embedded, may be nearly polar opposites. This may mean that some skills become either obsolete or even harmful in a new organizational sector. Moving across organizational sectors provides the opportunity to build new proficiencies. While this may be true for movement between any organizations, interviewees indicated that the impact is significant when moving between organizations in different sectors.

To determine the type of organizations systems engineers develop their skills, the team first identified the positions in chronological order. Then, job descriptions and interviews were utilized to capture the pertinent organizations. Results were then evaluated and compared among the multiple seniority levels.

Figure 27 shows the distribution of the organizational sectors that Helix interviewees have worked in so far during their systems engineering relevant careers.

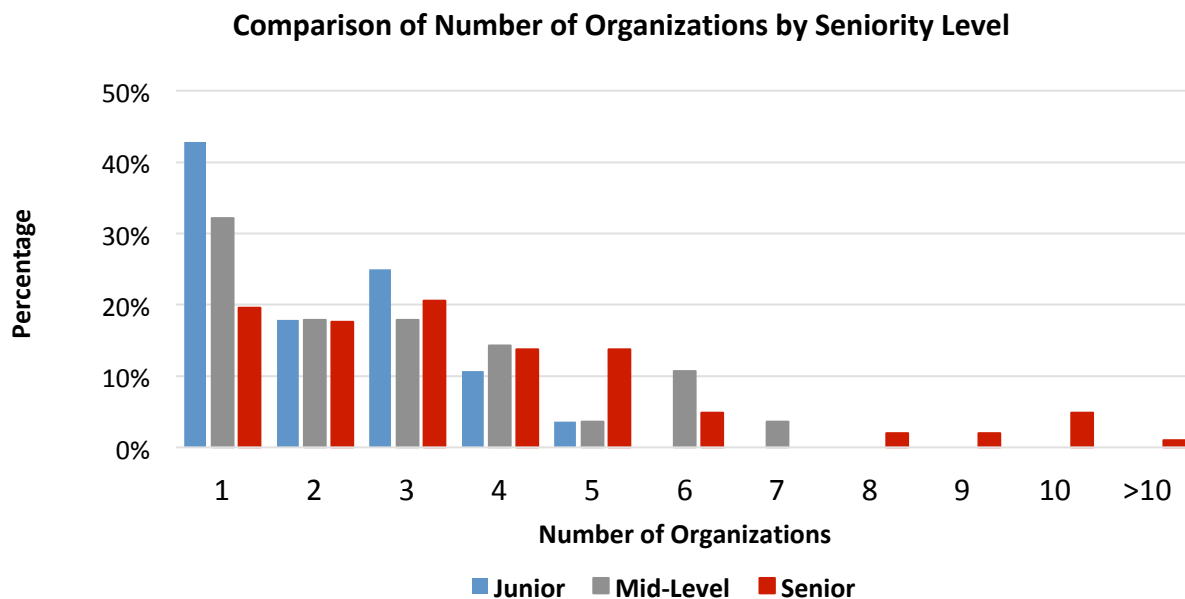


**Figure 27. Organization domain and systems engineer experience**

As it can be observed, government and industry organizations cover more than 90% of the organizations where junior, mid-level and senior systems engineers perform their activities. Only in few instances systems engineers have affiliation to an academic institution.

When an individual works within a single organization for a long period of time, he or she learns and internalizes the organization’s processes for systems engineering, builds a network of peers that they leverage to better perform systems engineering, and how to operate within the organization. All of these factors contribute to a systems engineer’s proficiency and effectiveness. However, moving to a new organization provides opportunities for gaining new proficiencies. Exposure to different processes or systems engineering approaches helps systems engineers better understand the conditions appropriate to different approaches, and improves their ability to tailor processes and approaches as appropriate. Working within a new culture provides opportunities to better understand the impacts of culture on the overall effectiveness of systems engineers. Though transitions might be difficult, they can provide valuable experiences.

Figure 28 shows the distribution of total number of organizations worked across the sample, divided by seniority.



**Figure 28. Distribution of number of organizations by seniority level**

Junior, mid-level, and senior systems engineers predominantly worked in six or fewer organizations. More than 40% of the junior systems engineers have worked in only one organization, as their careers have been generally much shorter. Over 30% of mid-level systems engineers and over 20% of senior systems engineers have only worked within a single organization. Those who fall within this category explained that they understood the organizational context so well and are satisfied with that context, that they see no need to make changes. Lastly, only the most senior systems engineers in the sample have worked in 8 or more organizations, as they generally have had the longest careers and, therefore, the most opportunities for movement between organizations.



## 4. CAREER PATHS OF CHIEF SYSTEMS ENGINEERS

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A chief systems engineer (CSE) has formal responsibility to oversee and shepherd the technical correctness of a system, often coordinating with many other engineers who have smaller scopes of responsibility. In many organizations, the CSE (or equivalent) is the highest technical position a systems engineer can play.

**CSE** – term used to identify a chief systems engineer equivalent in the *Helix* dataset.

In both the Helix dataset and the INCOSE dataset, the Helix team identified individuals considered “chief systems engineers”, regardless of their actual titles. In Helix, these are labeled CSEs. In the INCOSE dataset, the Helix team identified individuals who fulfilled the description of a chief systems engineer. There were many different titles associated with them. To distinguish between the Helix and INCOSE datasets, INCOSE CSE equivalents are called “ChiefX”.

**ChiefX** - term used to identify a chief systems engineer equivalent in the *INCOSE* dataset.

Because CSEs and ChiefXs were the most senior technical systems engineers in the samples, they provide examples of individuals who have successfully grown to become the most trusted and respected systems engineers in their organizations. The Helix team, therefore, believes that examining the career paths of CSEs and ChiefXs may provide some insights into how these individuals became so effective.

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### 4.1. EXAMINING THE CAREER OF CHIEF SYSTEMS ENGINEERS (CSEs)

The description of a career path is only useful to the extent that it provides valuable insights about how individual systems engineers can grow, mature, and develop their own careers. But what are the paths that lead to success? From the Helix interview data, a Chief Systems Engineer (CSE) is one of the most senior technical positions that a systems engineer can achieve. Individuals who became CSEs were able to do so because they had proven themselves to be effective throughout their careers, and had continually demonstrated the ability to take on increasing responsibilities. Hence, Helix considers the careers of CSEs worthy of further examination, since it can provide valuable insights to systems engineers early in their career to be develop into CSEs in future.

Helix identified 27 individuals in the interview sample who currently hold or have held the CSE position, for further analysis. Though many aspects of education and experiences were explored, a select few which provided particularly strong impacts on proficiency are discussed here: overall educational background; experiences across systems engineering lifecycle phases; and experiences across systems engineering roles.

In addition, there was a wealth of information available from the INCOSE SEP applications, especially on individuals applying for Expert Systems Engineering Professional (ESEP) certification. That information from INCOSE SEP data was also analyzed by Helix.

#### 4.1.1. EDUCATIONAL BACKGROUND OF CSEs

Each CSE in the sample had a bachelor's degree; for 18% of interviewees, this was the highest degree attained. Around 82 % of CSEs held at least one master's degree and 15% held a PhD. The most common bachelor's degrees majors among CSEs include Electrical Engineering and Mechanical Engineering covering more than two-thirds of the CSE dataset. Figure 30 illustrate the distribution of bachelor's degrees majors pursued by CSE's.

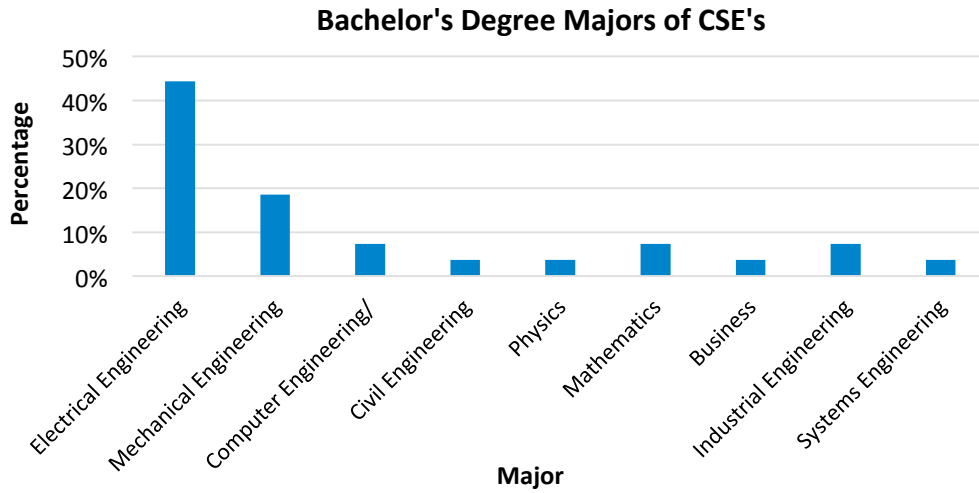


Figure 29. Distribution of bachelor's degrees across CSE's

In regard to master's degrees, Masters of Business Administration (MBA) is the most popular major covering almost 50% of the dataset. It is followed by systems engineering and electrical engineering respectively. Figure 30 illustrates the distribution of master's degrees attained by CSEs.

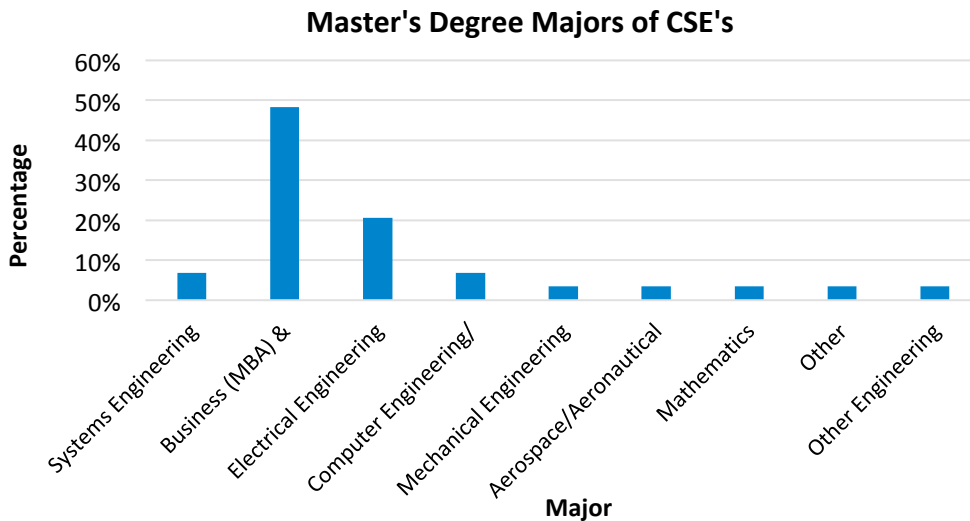


Figure 30. Distribution of master's degrees across CSE's

The following observations can be made from Figure 29 and Figure 30:

- 85% of CSEs have bachelor's education in engineering fields; a small number were educated in the physical sciences, mathematics, or business (<5% of each).
- Bachelor's education in systems engineering was also seen in less than 5% of CSEs. It was very common in the overall Helix sample for systems engineers to start out in specialty engineering fields, and the educational backgrounds of CSEs indicate that this was true for them as well.
- In general, engineering bachelor's education prepared CSEs with sufficient proficiency in Math/Science/General Engineering to perform detailed design work, do detailed analysis, or support test and evaluation.
- Only 7% of the CSEs have a master's degree in systems engineering; this is considerably lower than the overall rate of systems engineering graduate degrees in the total Helix sample (26%).
- Most CSEs indicated that they believed their experiences were sufficient and they did not believe that they would benefit enough to warrant the effort required to earn a master's degree in systems engineering.
- About a third of CSE's master's degrees (39%) were in engineering fields outside of systems engineering; this similar slightly higher compared to what is seen among other senior systems engineers in the sample (34 %).
- The most common master's field among CSEs was related to business (48%); generally, these were MBA degrees, though occasionally they were master's of science degrees related to more technical fields such as technology management. The CSEs with these degrees explained that they felt they had sufficient technical understanding but needed to learn more about business, management, finance, and other disciplines that support understanding business processes.
- The most common PhD concentration in the overall sample was systems engineering, but there is no single common field of doctoral study among CSEs; electrical engineering, geotechnical engineering, and atmospheric sciences have equal representation. Doctoral studies were not required for advancement for any of the CSEs. Instead, those with PhDs indicated their continued desire to learn and grow and improve their understanding of specific disciplines was their motivation.

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#### **4.1.2. EXPERIENCES ACROSS SYSTEMS ENGINEERING ROLES FOR CSEs**

All of the CSEs in the sample have experiences across either four or five lifecycle phases, but none of the CSEs have experienced all six of the lifecycle phases. Figure 31 provides insight into the order in which CSEs experienced the systems lifecycle.

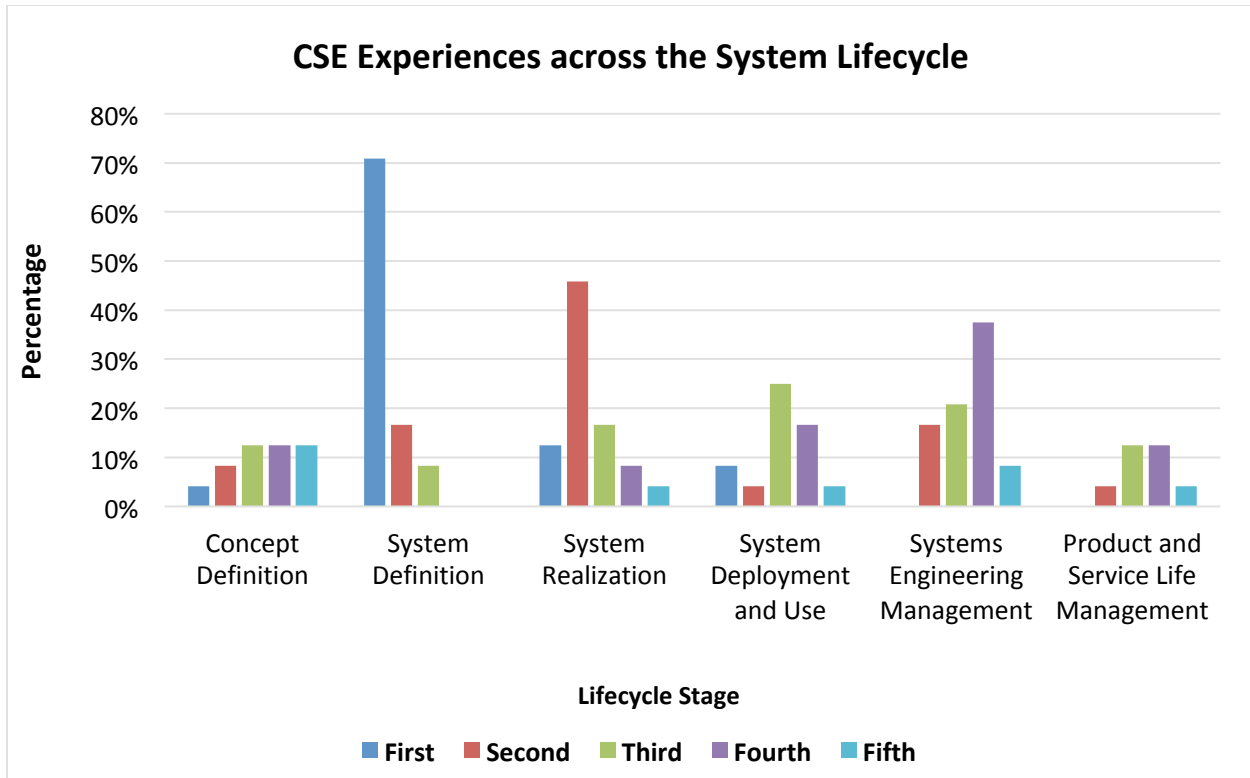


Figure 31. Order of Exposure to Lifecycle Phases Experienced by CSEs

There were a few clear patterns in how CSEs moved through the systems lifecycle:

- All CSEs have experienced *System Definition*, *System Realization*, and *Systems Engineering Management*.
- The most common point of entry for CSEs was System Definition; it was either the first or second aspect of the lifecycle experienced by 74% of CSEs. The most common pathway for entry into systems related work was through work as a specialty engineer. This detailed work was necessary to gain some depth – to understand how things “really work” and the problems that can be encountered when they try to design something. These Experiences impact the Math/Science/General Engineering and System’s Domain and Operational Context proficiency areas. Also, many CSEs experienced leading design work early in their careers, which would improve the Technical Leadership and Interpersonal Skills proficiency areas. It is worth noting that this parallels the patterns seen in among other senior systems engineers – so appears to be more of a trend of the experiences of systems engineers over a specific period of time (generally, 10-20 years ago) than a differentiator for CSEs.
- 83% of the CSEs had experienced *System Realization*. Systems engineers who had experience in manufacturing, which falls into *System Realization*, explained that these *Experiences* are valuable because they help engineers understand the practical

considerations and issues of implementing a design. Understanding the basic constraints on the common manufacturing techniques was stated as very valuable in improving design work and limiting the need for redesign.

- For *Systems Engineering Management*, all CSEs in the sample were also *Technical Managers*. The related activities: planning, configuration management, decision management, etc. are all part of the CSE position. In general, these types of activities were reported to help in the development of *Technical Leadership*, *Interpersonal Skills*, and *Systems Engineering Discipline proficiencies*.
- *Concept Definition* includes working directly with stakeholders to identify the problem and “true needs” (as opposed to a stakeholder’s assumptions about the right type of solution). Gaining this type of understanding first-hand gives systems engineers the opportunity to improve their understanding of the vision for the system and how it will be used, supporting growth in *System’s Domain and Operational Concept* and *Systems Engineering Mindset* proficiencies. Communicating directly with customers also enables systems engineers to build their skills not just in general communication, but also in the translation of non-technical information for a technical audience and vice versa. This provides an opportunity for improving *Interpersonal Skills* proficiencies. The majority of CSEs have had these *Experiences* – and often fairly early in their careers –helping them grow as systems engineers.
- Among CSEs, 60% of those who started in *System Deployment and Use* gained experience in the operation and maintenance of relevant systems as members of the US military. The remaining 40% also worked as operators and maintainers, but *working* in industry. Through these *Experiences*, CSEs had the opportunity to understand how a system should operate, what the common processes and procedures were in relation to a system, and to understand the problems that existing systems have. All of these activities provided opportunities to improve the systems engineer’s *System’s Domain and Operational Concept* proficiency. They also provide key insights about the overall lifecycle of a system, which can improve *Systems Engineering Discipline* proficiency. All of the CSEs who began their careers in *System Deployment and Use* stated that the understanding of issues that can lead to maintenance problems and issues encountered with operating these systems such as counterintuitive interfaces gave them better insights when they eventually began doing design work. These insights better enabled them to do technical tradeoffs and also helped them to better understand the importance of working through a systems concept of operations (CONOPS) early in the design phase. These *Experiences*, then, can improve their proficiencies in *System’s Domain and Operational Concept* and *Systems Engineering Mindset (Abstraction and Foresight)*, as well providing specific insights into lifecycle considerations for *Systems Engineering Discipline*.
- No matter where they started in the systems lifecycle, CSEs cited benefits in later phases they experienced. For example, CSEs starting in testing (*System Realization*, 13%) stated they gained insights into the unintended consequences of certain design decisions and these insights helped them avoid some of these pitfalls when they began design work

(*System Definition*). Starting in *Concept Definition* – working on stakeholder needs and CONOPS – provided an opportunity to better understand the “end state” or “big picture” – and this helped keep the system goals in mind during the design process.

In the sample of CSEs, there do not seem to be standard patterns to move through the systems engineering lifecycle, except that starting in *System Design* is most common and those who do not start in system design most commonly next move into *System Design*. The order seems less critical than having a mixture of experiences across the lifecycle and having a mindset that enables systems engineers to draw connections across these experiences to enable understanding and growth.

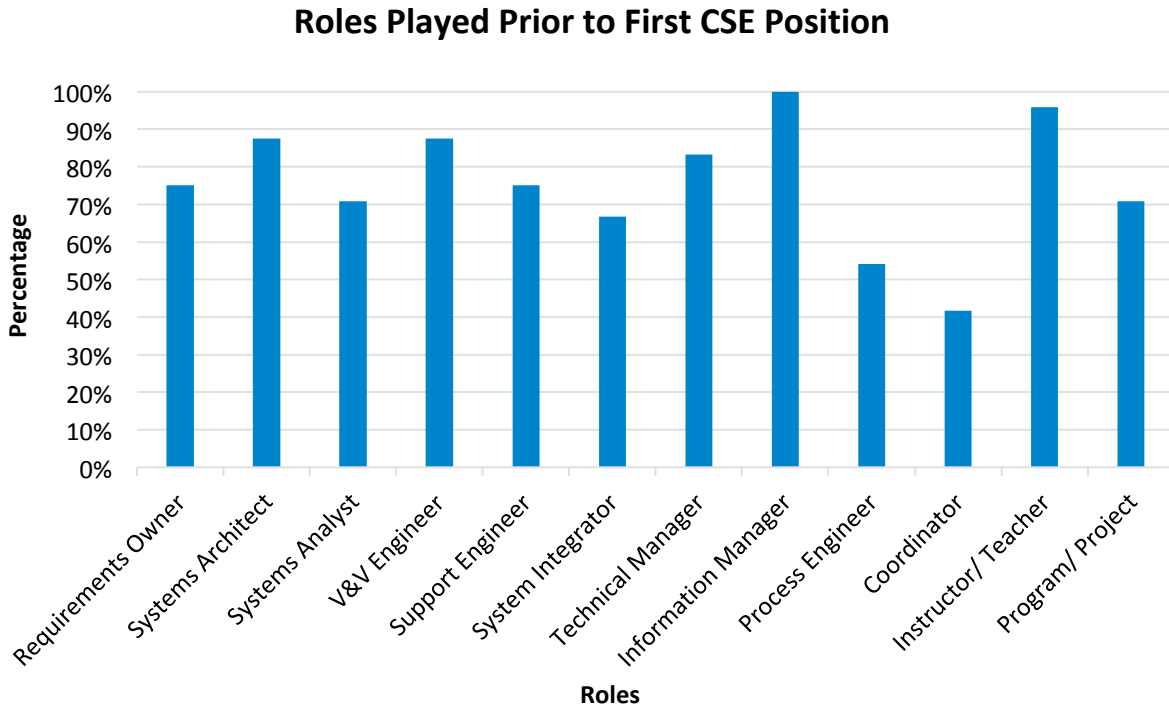
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#### **4.1.3. EXPERIENCES ACROSS SYSTEMS ENGINEERING ROLES FOR CSEs**

There are multiple types of roles that systems engineers can play within a single position or even a single phase of the systems lifecycle. To better understand how individuals grew into their CSE positions, the roles played by CSEs in the Helix sample prior to their first CSE position, and during their first CSE position were analyzed. All roles played by CSEs throughout their careers, up to the point of their participation in Helix interviews, were also analyzed. The reason this is important is this illustrates the roles of the career paths *leading up to* becoming a CSE, which can provide critical examples for systems engineers hoping to grow into CSEs.

##### **Roles Played Prior to First Chief Systems Engineering Position**

Figure 32 provides an overview of the roles played by CSEs *prior* to their first CSE position, to provide insight into the career paths that helped these individuals become CSEs. This has been updated to reflect the *Atlas 1.1* role framework. Note that the roles of *Concept Creator*, *Detailed Designer*, and *Systems Engineering Champion* are not included in the analysis. This is because data on these roles was not collected consistently throughout the sample; additional follow up will be required to enable analysis for these roles.



**Figure 32. Roles Played by CSEs Prior to Their First CSE Position**

Insights from analyzing the roles played by CSEs prior to their first CSE position include:

- All of the systems engineers who would become CSEs worked as *System Designers* and *Technical Managers* prior to their first CSE position. As discussed earlier, these roles are generally a critical aspect of the CSE position, so it is reasonable that individuals would have to prove their abilities in other roles prior to being offered a CSE position.
- The less common roles (50% or lower) are *Process Engineer*, *Organizational Manager*, and *Program/Project Manager*. It is possible that CSEs did work in these areas, but this simply did not make it into their descriptions or discussions of the positions they've played.
- The roles of *Instructor/Teacher*, and *Program/Project Manager* are generally less common in the Helix sample (21%, and 19%, respectively). The rates among CSEs are more than twice that seen in the general sample.
- One CSE stated that he had performed the *Organizational Manager* role as a favor to the organization – to fill a role that was needed as an interim measure – but with the expectation that he would then pursue a technical track. Other CSEs explained that in their organizations, spending some time as an *Organizational Manager* is a requirement before one can become a CSE. Time spent as an *Organizational Manager* primarily provides insights into the functioning of the organization, and may also provide some insight into processes and opportunities to grow a network of experts within an organization, corresponding with growing proficiencies in *Technical Leadership*.
- Over a quarter of the CSEs have been instructors of in-house training or professors at

universities focusing on teaching systems engineering or related subjects. These roles improve proficiency in the subject matter not just through the creation of course materials but also through interactions with the students and the application of real-world *Experiences* in an academic setting.

- The role of *Program/Project Manager* has been played by nearly half the CSEs prior to their first CSE position, as in many organizations the *PM* role was considered a role with higher responsibility than that of CSE. In these cases, the CSE acted as a *Program/Project Manager* on a smaller or less complex system before taking on CSE positions on a larger and/or more complex system. CSEs explained that playing this role helped them to better understand not just the technical constraints of a system, but also to build an appreciation for schedule, budgetary, and resource constraints as well as the overall business case for systems development, and also provided the opportunity to understand the customer's perspective in a different way. This role was particularly strong in helping develop proficiency in the *Technical Leadership* area.

The final aspect of the roles of systems engineers is more general than Sheard's twelve roles (1996) and that is the overarching concept of leadership. Each CSE described having several leadership positions early in their careers, starting generally as small group leaders on simple tasks and continually taking on increasing leadership roles throughout their careers. Several of the systems engineering roles described above may have a distinct leadership component. For example, a *Requirements Owner* may start by simply recording requirements in a database, progress to leading a small team to manage the database, then progress to having responsibility for coordinating with the customer (adding the *Customer Interface* role) to generate the best set of requirements while overseeing the team that manages the requirements. These types of patterns – with leadership responsibilities even in more detail-oriented roles – is a common pattern for CSEs, indicating that it is through leadership activities that systems engineers can provide their greatest value.

### **Role Played during First Chief Systems Engineering Position**

If someone wants to become a CSE, what does that really mean? The Helix team examined the roles in the descriptions of the each first CSE position from resumes and interview data, and their commonality within the sample of CSEs, as shown in Figure 33. These descriptions provide insight into what it commonly means in the systems engineering community to be a CSE. Note that the roles of *Concept Creator*, *Detailed Designer* and *Systems Engineering Champion* are not included; this is because the data on these roles was not collected consistently and additional follow up will be required.



### Roles Played During the First CSE Position

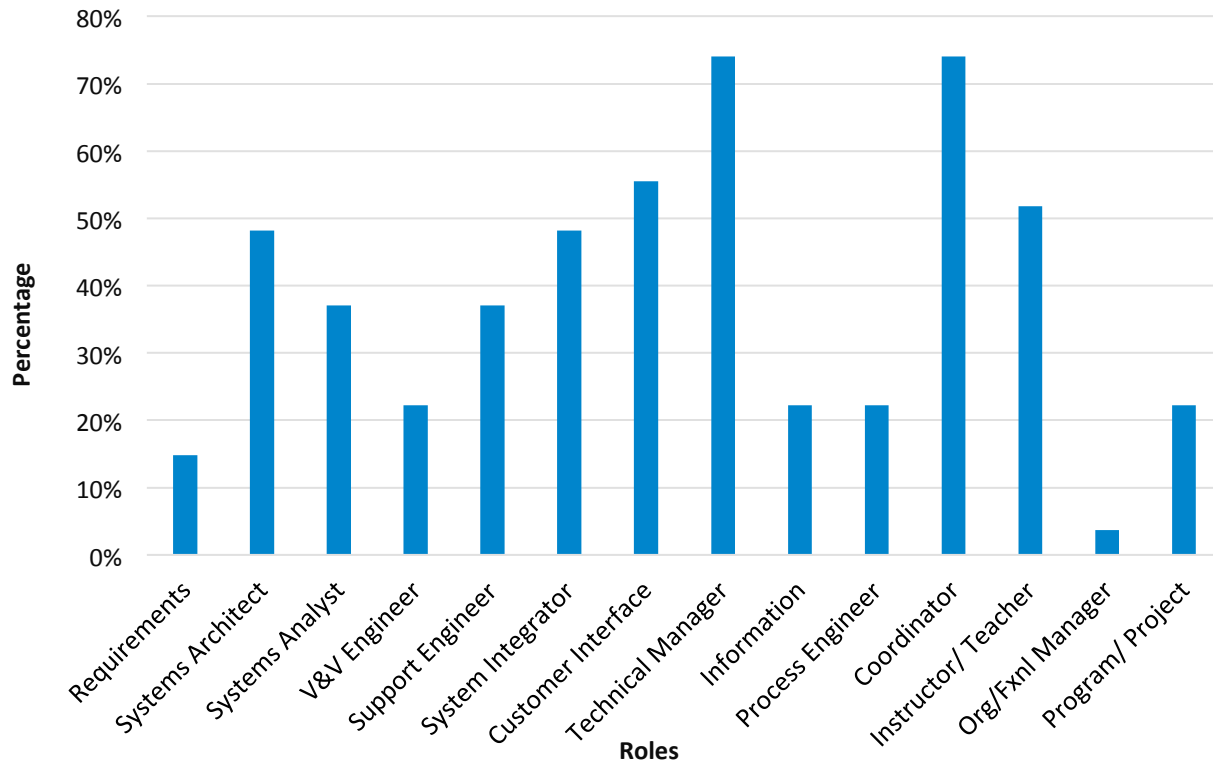


Figure 33. Roles Played by CSEs During Their First CSE Position

Insights from analyzing the roles played by CSEs during their first CSE position include:

- All of the CSEs describe the role of *Technical Manager* as a part of the CSE position, and 95% described the role of *Coordinator* as another critical aspect of the position. Over 3/4 of CSEs have had a critical role as *Technical Manager* and *Coordinator* as part of their first CSE position. One CSE explained that the variety of roles played in the CSE position is somewhat dependent on the organization. For example, when he was a CSE at a small organization, he had to be a “jack of all trades” and therefore played a multitude of roles; now at a much larger organization, his role of CSE is more specialized because there are more people available to perform other roles. Both, he explained, had benefits for development of systems engineering related skills.
- The more detail-oriented roles were less commonly seen as part of the CSE position, but did occur. Often, when a role was not directly performed by the CSE, interviewees explained that the role was simply performed by a member of the team and overseen by the CSE.
- It is also rare for a CSE to function as a *Program/Project Manager*. In the instances where this did occur, it was generally on a smaller project, where the overall smaller

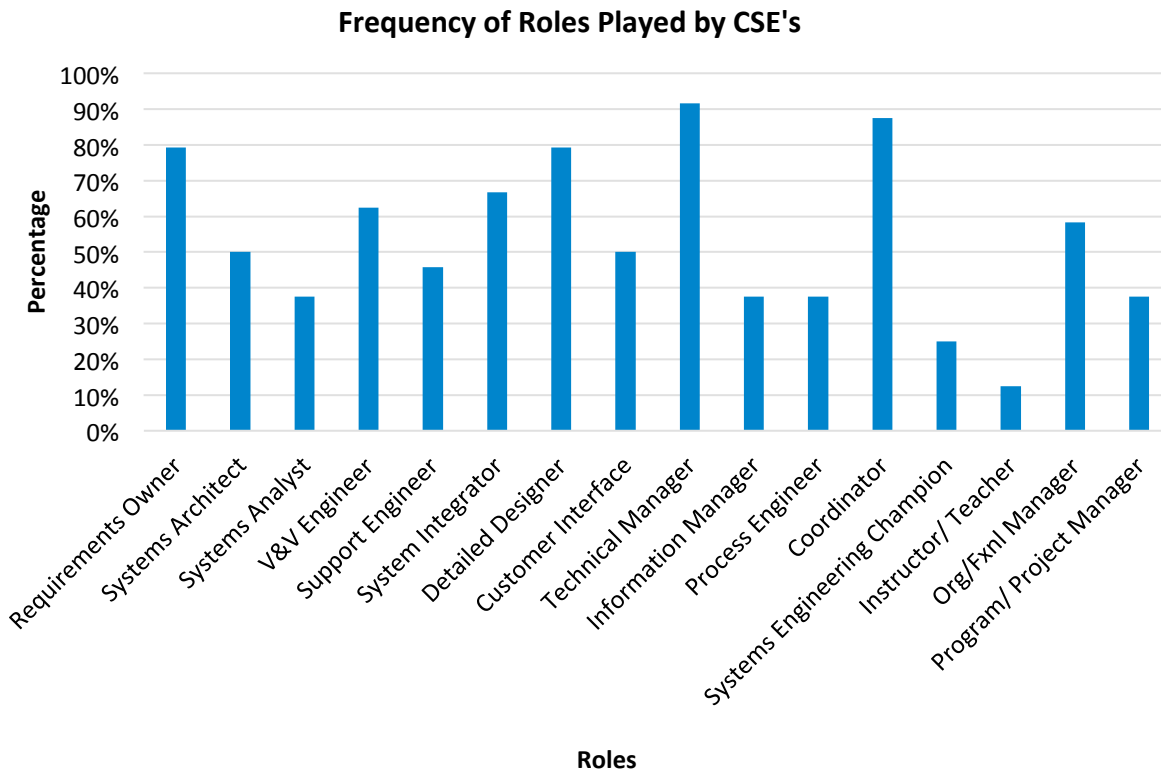
staff required that single individuals take on multiple positions.

- *Organizational Manager* is again a very uncommon role for a first CSE position, as the focus for CSEs is generally technical over administrative.
- None of the CSEs had detailed V&V responsibilities in their initial CSE roles because the CSE must oversee a team of systems engineers and other engineers. Occasionally a CSE would play the role of subject matter expert or detailed designer in a CSE position, but this always occurred much later in their careers, often as part of a smaller project or a proposal.

The roles played in a first CSE position would tend to further proficiencies in *System’s Domain and Operational Context*, *Systems Engineering Discipline*, *Systems Engineering Mindset*, *Interpersonal Skills*, and *Technical Leadership*. Though a CSE may not lose skills in *Math/Science/General Engineering*, however, because the role(s) played seldom focus on these areas, it would be unlikely for a CSE to gain proficiency in these areas.

### **Roles Played throughout CSEs’ Careers**

Figure 34 provides an overview of the roles played by CSEs throughout their careers, spanning up to their participation in Helix.



**Figure 34. Roles Played by CSEs Throughout Their Whole Careers**

The following observations can be made from Figure 34:

- Most frequent roles among CSEs in the Helix sample include *Technical Manager (92%), Coordinator (88%), Requirements Owner (79%) and Detailed Designer (79%)*.
- Even in areas where less than 100% of CSEs have played a role, a much higher percentage of CSEs have played the role than seen in the general Helix sample. For example, 79% of CSEs have played the role of *Requirements Owner* while in the overall Helix sample, this number is just over 47%.

It is clear that the percentage of CSEs who have played these roles continues to rise even after their first CSE position and overall, the percentage of CSEs who have played these roles is considerably higher than in the general Helix population. This indicates that CSEs overall have experiences playing a wider range of roles and that this broad variety of roles continues throughout their careers; it does not stop when they earn the title of “Chief Systems Engineer”.

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## 4.2. INSIGHTS FROM INCOSE ESEP ANALYSIS

Among the three levels of INCOSE SEP certification, ESEP is the highest category. ESEP applicants are required to submit information of twenty or more years of work history relevant to systems engineering, and are therefore expected to possess significant experience in systems engineering. In the seniority levels defined by Helix, ESEPs that are successfully certified are Senior systems engineers.

As discussed above, analyzing the career paths of CSEs provides some insights for career development. Similarly, within the INCOSE SEP data from certified ESEP applicants, a subset of those who have held a CSE position or a position equivalent to CSE was analyzed. A category called ‘ChiefX’ was identified, that included certified ESEPs who have held CSE titles or other equivalent titles, specifically, Chief Engineer, Chief Architect, Chief Systems Architect, Chief Principal Engineer, and Chief of Systems Engineering. A comparison of CSEs from the Helix interview data and ChiefXs from INCOSE SEP data was used to partially validate the Helix sample against a larger diverse international sample of systems engineers.

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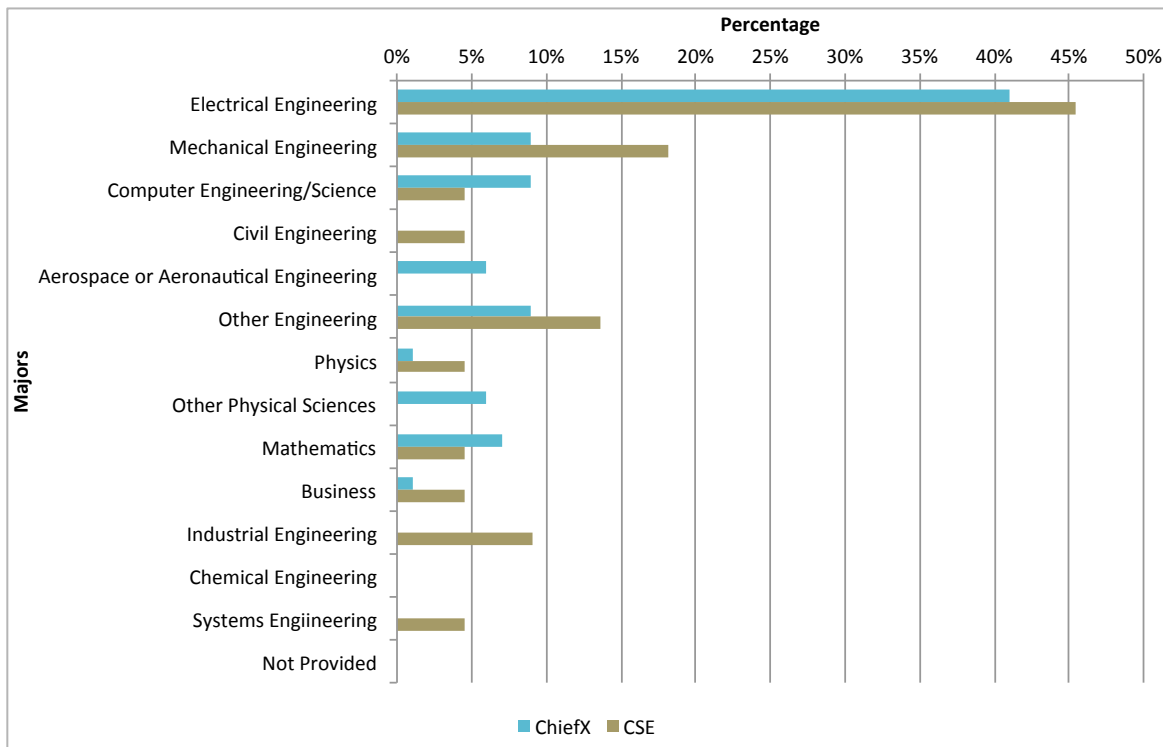
### 4.2.1. EDUCATION OF CHIEFXS

Table 9 compares the highest degrees obtained by CSEs in the Helix interview data and ChiefXs from the INCOSE SEP data. The highest degrees compare well between the two samples. The CSEs in the Helix sample have a slightly higher rate of master’s degree attainment, while the ChiefXs a slightly higher rate in PhDs.

**Table 9. Highest Degree Attained for CSEs (Helix interviewees) and ChiefXs (ESEPs)**

| Degree Level | CSEs | ChiefXs |
|--------------|------|---------|
| Associate's  | 0%   | 0%      |
| Bachelor's   | 20%  | 23%     |
| Master's     | 64%  | 60%     |
| Doctorate    | 16%  | 17%     |

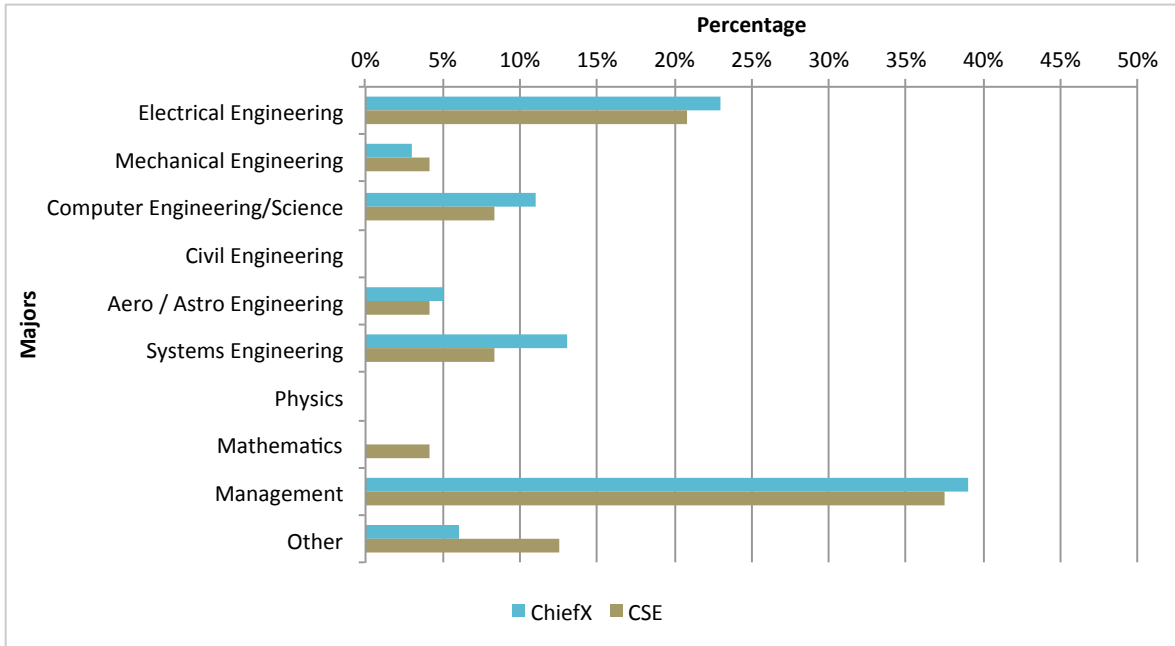
Figure 35 compares the bachelor's degree majors of CSEs and ChiefXs. Electrical engineering comes out as the most popular major in both samples. Though there are some variations, mechanical engineering, computer engineering / science are the next popular majors for ChiefXs. There are some majors such as civil engineering, aerospace or aeronautical engineering, and industrial engineering that are found in one sample but not in the other.



**Figure 35. Comparison of Bachelor's Degree Majors between CSEs and ChiefXs**

Figure 36 compares the master's degree majors of CSEs and ChiefXs. The most prevalent master's degree major attained was in the area of business – 38% of the CSEs and 39% of the ChiefXs sought a management master's. Most frequently this was an MBA or other management variant. A little less than a quarter of CSEs and ChiefXs pursued a master's in

electrical engineering. Almost 10% of CSEs and 13% of ChiefXs complete a master’s in systems engineering. The trends observed in master’s degree majors indicate similar education profiles for both the CSEs and the ChiefXs.



**Figure 36. Comparison of Master’s Degree Majors between CSEs and ChiefXs**

As shown in Table 9, 17% of the ChiefXs have doctorate degrees. This is much greater than in the Helix sample, of which 9% of CSEs have doctorate degrees. Similar to findings from the Helix sample, there was minimal convergence in any specific academic discipline for doctoral study. Of the ChiefXs, 13% of the applicants sought a doctor of philosophy in engineering, mechanical engineering, computer science and systems engineering/integration; the other 4% includes doctorate degrees such as Applied Mechanics and Juris Doctor.

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#### **4.2.2. CAREER ROLES PLAYED BY CERTIFIED ESEP’S AND CHIEFXS**

Helix identified the *Atlas* roles among INCOSE ESEP applicants, using text-based searches. Figure 37 compares the roles played by senior systems engineers and CSEs from the Helix interview data, compares the roles played by certified ESEPs (non ChiefXs) and ChiefXs from the INCOSE SEP data. In Figure 38, they are provided along with the roles for senior systems engineers in Helix and ESEPs for the INCOSE dataset. This provides a point of comparison – i.e. are there clear differences in the roles that senior systems engineers who have become CSEs played compared to those of who have not yet reached that level?

### Comparison of Career Roles of Helix and INCOSE ESEP's and ChiefX's

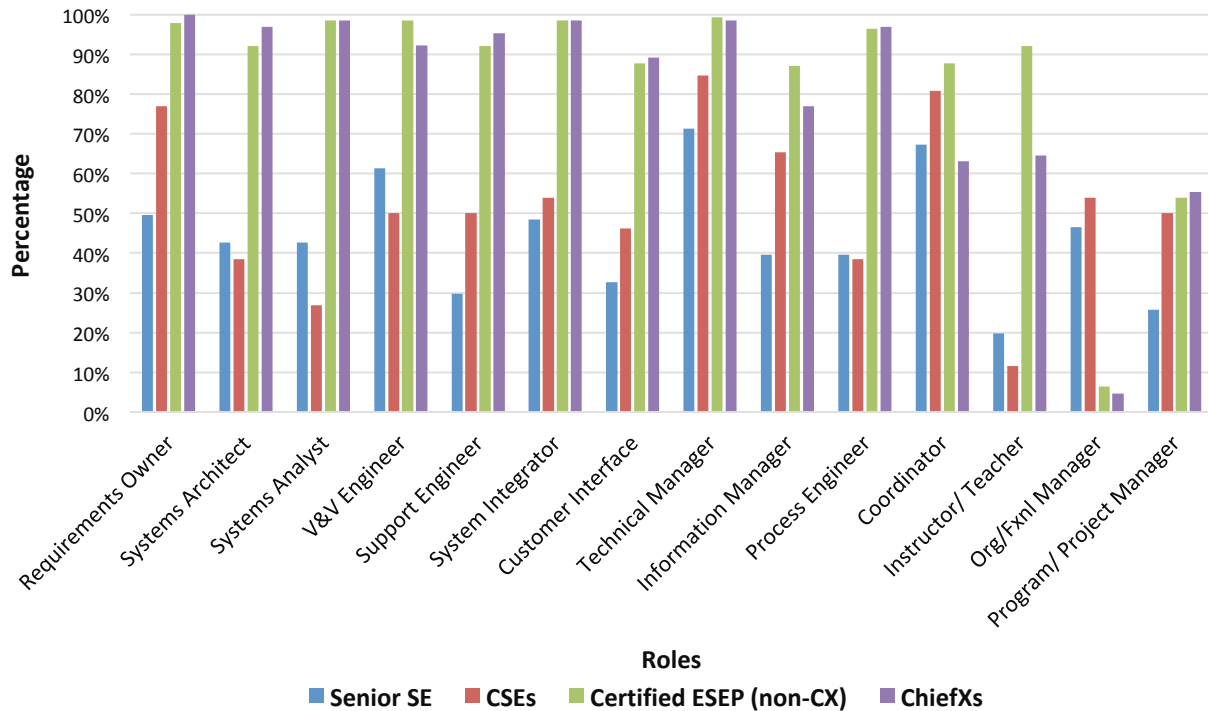


Figure 37. Comparison of Roles Played Throughout Career between Helix Interview Data and INCOSE SEP Data

The career roles played by the INCOSE certified ESEPs and ChiefXs most closely resemble the roles played by the CSEs in the Helix sample. Since INCOSE has an extremely selective process for certifying ESEPs, the individuals that receive the certification have *Experiences* equivalent to the CSEs in the Helix sample rather than the senior systems engineers. Therefore, the senior systems engineers, while they are more seasoned than junior or mid-level systems engineers, do not, in general, have the breadth and depth of *Experiences* in different roles as compared to the CSEs, the ESEPs (non-ChiefXs), and the ChiefXs.

Additional insights include:

- The *Organizational/Functional Manager* role is more common in the Helix interview sample. This could imply that either those who apply for ESEP are more likely to be in a technical track and therefore not have the experience in management to take on this type of role; or ESEP applicants omitted reporting such roles since the application form solicited only systems engineering related tasks and functions.
- The Helix sample identified the most seasoned systems engineers who hold critical systems positions are only occasionally instructors at some point in their career. But in the ESEP applications, the role of instructor is called out more explicitly, and applicants are requested to provide details on training. This may have led to a higher reporting rate among ESEPs than CSEs among Helix interviewees for the role *Instructor*.

- The Helix sample showed that systems engineers often play multiple roles while they are in a single position. This finding was mirrored in the ChiefX subset. More than half of the ChiefXs had compound titles, and therefore it was assumed they were actively performing multiple roles. The most frequent keywords in ChiefX compound titles indicate that organizational leadership is typically a complementary position to CSE. Three of the most frequent keywords in ChiefX compound titles were Manager (17%), Lead (12%), and Director/Head (11%). The other frequent keyword, Architect (8%) indicates that CSEs hold technical and system-specific roles.
- For all ChiefXs who held 3 or more ChiefX titles at some point in their careers (15% of the ChiefX subset), each individual progressed into larger and more complex systems. The Helix sample showed that one common career path for systems engineers' stems from a highly technical position, and through the growth of their careers, the systems engineers take on more responsibility and leadership roles, which correlates with growing of interpersonal skills.

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#### 4.2.3. ROLES PLAYED IN FIRST CHIEFX POSITION

Figure 38 provides a comparison of the roles played by ChiefXs in their first ChiefX position and roles played by CSEs in their first CSE position from the Helix interviewee dataset.

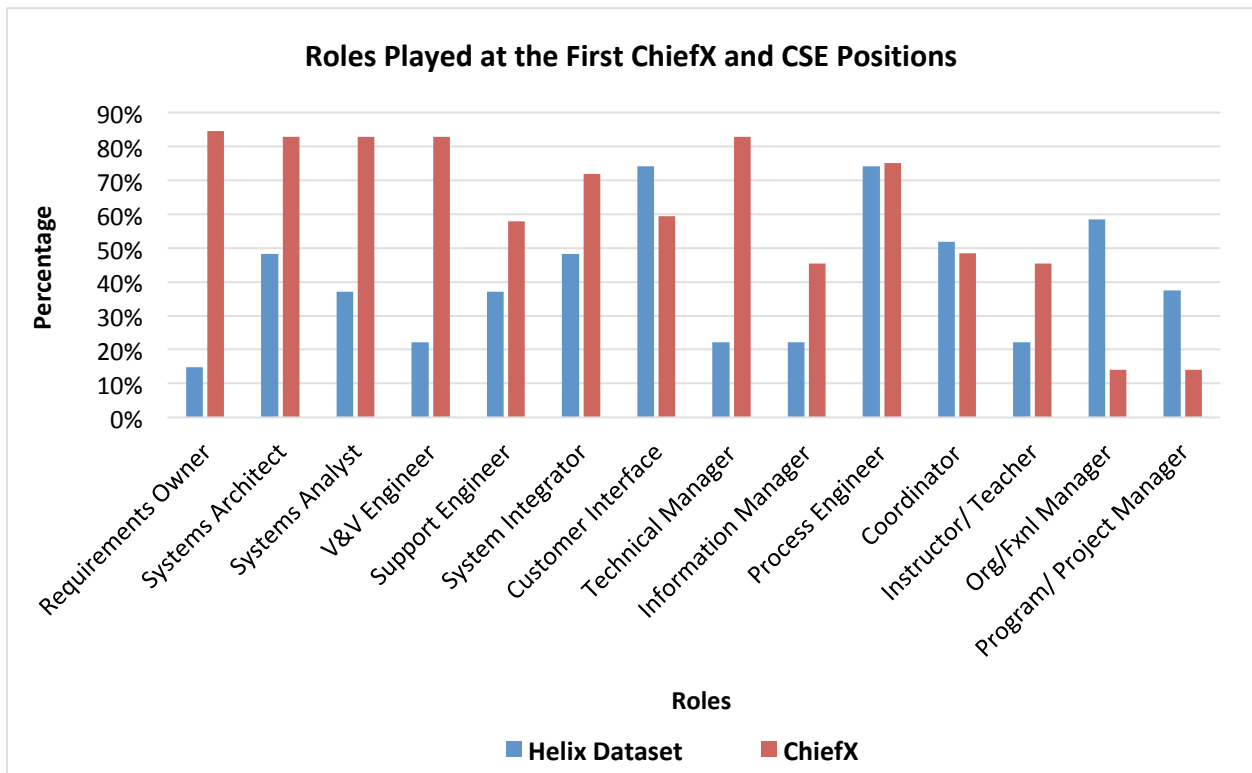


Figure 38. Roles Played in First ChiefX and CSE Positions

As is seen in Figure 38,

- The roles played most commonly during the first ChiefX position are *Requirements Owner, Technical Manager, Validation and Verification Engineer, System Designer, and System Analyst*.
- The CSE sample experienced technical and programmatic management aspects of systems rather than the more technical system lifecycle roles that were experienced by the ChiefXs.
- Almost half (45%) of the ChiefXs played ten or more different roles in their first ChiefX position - 35% played between 5 and 9 roles (inclusive), and 20% played less than 5 roles. Only the *Program Manager* and *Organizational/Functional Manager* roles are performed by less than 40% of the ChiefXs.
- Almost half of the ChiefXs played the role of *Instructor/Teacher* while in their first ChiefX position. This indicates the knowledge base of these individuals, and their willingness to share their critical understanding and experiences with others, ultimately leading to an improvement of their organization. This aligns nicely with the Helix data, wherein over half of CSEs played this role during their first CSE position.

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#### 4.2.4. VALUE OF INCOSE SEP ANALYSIS FOR ATLAS

The INCOSE data was an excellent benchmark for the Helix sample. Characteristics and patterns identified in *Atlas* were further evidenced via comparison of certified ESEPs and ChiefXs with the senior systems engineers and CSEs from the Helix interview sample. There were no major discrepancies that would indicate a need for reassessment of *Atlas*. INCOSE SEP applications provided a wealth of data for use in identifying the *Education* and *Experience* backgrounds of those who have been systems engineers in industry for over 20 years, and are certified as knowledgeable, experienced and accomplished professionals in systems engineering.



## 5. BRINGING THINGS FULL CIRCLE: RELATING CAREER PATHS TO PROFICIENCY

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This section provides highlights on the linkages between a systems engineer's career path and proficiency. It utilizes self-assessments of proficiency and compares them with the Helix team's analysis of individuals with similar self-assessments. Sections 5.1 and 5.2 also highlight the Capstone project by Mr. Matthew Partacz.

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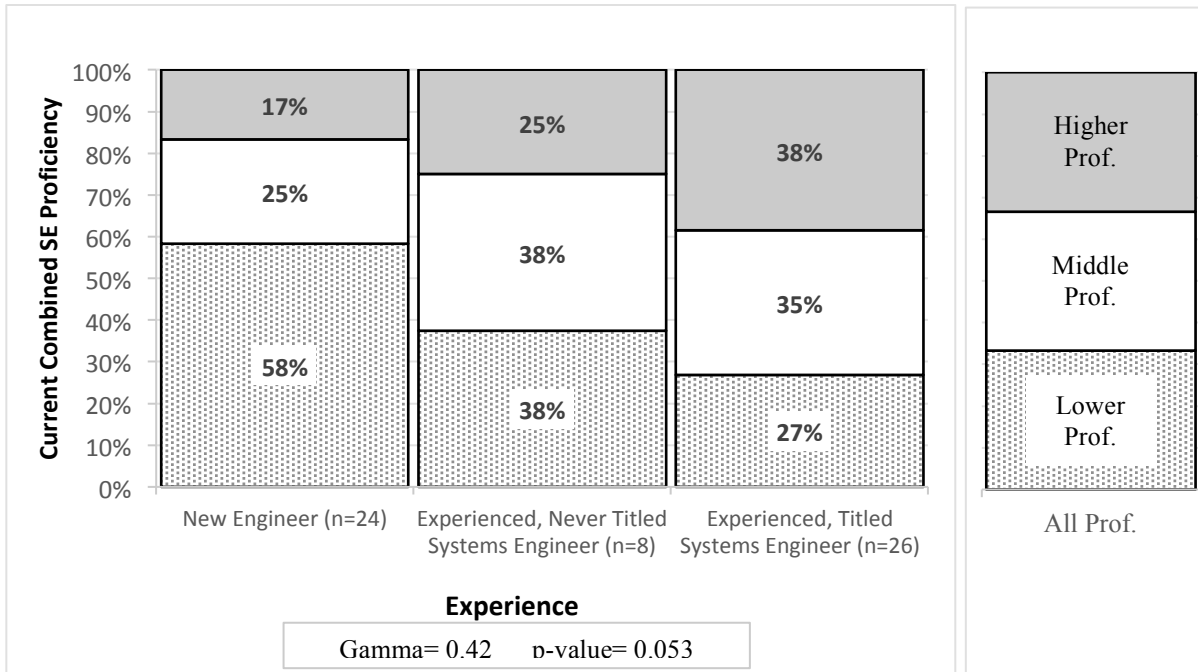
### 5.1. CAPSTONE PROJECT RESULTS: LINKING CAREER PATHS WITH PROFICIENCY

*The following highlights results of a capstone project conducted in conjunction with Helix. Additional details on the results highlighted in Section 5 may be found in Building a Better Business Case for Systems Engineering: The Relationship between a Systems Engineer's Career Path, Proficiency and Project Performance written by Matthew Partacz (2017). **Note that for this analysis, the proficiency assessments are reported on a scale of 1-10 rather than the 1-5 scale used in Atlas 1.1. This translates to the Atlas scale by dividing by 2. (E.G. an "8" below is the same as a "4" in Atlas).***

In order to prove the relationship between an individual's career path and their proficiency of Systems Engineering (SE), the following hypothesis was assessed:

*Career path has a quantifiable impact on an individual's systems engineering (SE) proficiency.*

The analysis of the collected data shows that there are identifiable and significant relationships between career path and systems engineering proficiency. Figure 39 shows that for a new engineer, only 17% have higher systems engineering proficiency and 58% have lower systems engineering proficiency, while for an experienced engineer who has been titled a systems engineer, 38% have higher systems engineering proficiency and 27% have lower systems engineering proficiency. The explored relationship has a confidence of 94.7%. Overall, there is a very strong positive relationship between combined SE proficiency and experience.



**Figure 39. Experience vs. Current Combined SE Proficiency**

In addition to looking at the combined systems engineering proficiency, each of the six areas of systems engineering proficiency were compared to career path and are summarized in Table 10.

**Table 10. Summary of SE Proficiency vs Experience, non-parametric statistical analysis**

| SE Proficiency                        | Gamma | p-value |
|---------------------------------------|-------|---------|
| Math/ Science/ General Engineering    | -0.32 | 0.880   |
| Systems' Domain & Operational Context | 0.51  | 0.025   |
| Systems Engineering Discipline        | 0.53  | 0.015   |
| Systems Engineering Mindset           | 0.53  | 0.022   |
| Interpersonal Skills                  | -0.01 | 0.507   |
| Technical Leadership                  | 0.50  | 0.023   |
| Combined SE                           | 0.42  | 0.053   |

Exploring the results shown in Table 10 Math/ Science/ General Engineering Proficiency was found to have a Gamma of strong negative relationship to experience with a confidence of 12.0%. This result is due to the limitations of non-parametric statistical analysis, in which the order of new engineer, experience and never titled systems engineer, and experienced and titled systems engineer is assumed to be in increasing order. However, it was determined that from all HELIX interviews conducted that an experienced and titled systems engineer would have the lowest math/ science/ general engineering proficiency, and an experienced and never titled systems engineer would have the highest math/ science/ general engineering proficiency.

This fact voids this particular non-parametric statistical analysis. Further exploring the results shown in table x, Interpersonal Skills was found to have a weak to non-existent relationship to experience with a confidence of 49.3%. This relationship suggests interpersonal skills are not improved from experience, however an increased sample size would be required to confirm the relationship seen from the HELIX sample. All other SE proficiencies shown in table x were found to have very strong positive relationships to experience with the confidence no lower than 97.5%.

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## 5.2. CAPSTONE RESULTS: PROFICIENT SYSTEMS ENGINEERS IMPROVE PROJECT PERFORMANCE

Helix partnered with a master’s student to explore the relationship between SE proficiency and project performance within the Helix dataset.

In order to prove the relationship between an individual's proficiency of Systems Engineering (SE) and their project performance, the following hypothesis was assessed:

*An individual’s systems engineering proficiency yields quantifiable improvements in program execution (e.g., improved cost performance, schedule performance, and technical performance).*

- Examination of the collected data comparing individual’s systems engineering proficiency and program execution was determined to be inconclusive. This portion of the study had a limited sample size of 28, and cannot be used identify any patterns or to generalize an entire population. Moreover the relationships seen, at best, have a 57.5% confidence. With a greater overall sample size, response distributions should normalize and better relationships can be observed with a greater confidence.
- Findings for the relationship between systems engineering proficiency and overall program execution are summarized in Table 11.

**Table 11. Summary of SE Proficiency vs. Overall Project Performance, Non-parametric statistical analysis**

| SE Proficiency                        | Gamma | p-value |
|---------------------------------------|-------|---------|
| Math/ Science/ General Engineering    | 0.00  | 0.500   |
| Systems' Domain & Operational Context | -0.12 | 0.614   |
| Systems Engineering Discipline        | -0.11 | 0.608   |
| Systems Engineering Mindset           | -0.03 | 0.530   |
| Interpersonal Skills                  | 0.04  | 0.465   |
| Technical Leadership                  | 0.08  | 0.425   |
| Combined SE                           | -0.20 | 0.685   |

Insights resulting from this limited study could help organizations make a business case for investments in systems engineers. Organizations could also better identify candidates for

systems engineering positions and create workforce development programs to improve their overall systems engineering capability.

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## 5.1. LINKING PROFICIENCY TO CAREER PATHS IN THE HELIX DATASET

Using the approach developed by Partacz (2017), the Helix team linked the career path dataset with individuals who had completed self-assessments of their proficiencies. While the team notes that self-assessments can be biased, they nevertheless are useful in understanding the patterns between what an individual has done and what she believes she has learned.

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### 5.1.1. OVERVIEW OF ATLAS PROFICIENCY MODEL

Proficiency is defined in *Atlas* as “knowledge, skills, abilities, behaviors, and cognitions” (KSABCs). Specifically, these are the KSABCs identified throughout the Helix dataset as critical for systems engineers to be effective. The *Atlas* proficiency model consists of six proficiency areas – groupings of related KSABCs – based on the Helix interview data, as shown in

Figure 40 below. An overview of the model is provided here and additional detail is provided in context with the results for proficiency assessments for each area. For the full *Atlas* proficiency model, please see *Atlas 1.1*.

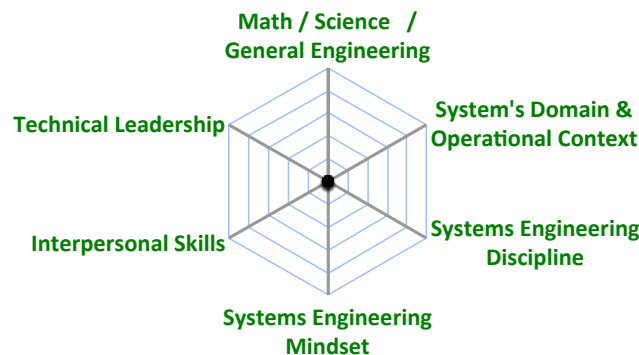


Figure 40. Proficiency Areas for Systems Engineers

1. **Math/Science/General Engineering:** Foundational concepts from mathematics, physical sciences, and general engineering;
2. **System's Domain & Operational Context:** Relevant domains, disciplines, and technologies for a given system and its operation;
3. **Systems Engineering Discipline:** Foundation of systems science and systems engineering knowledge;
4. **Systems Engineering Mindset:** Skills, behaviors, and cognition associated with being a systems engineer;

5. **Interpersonal Skills:** Skills and behaviors associated with the ability to work effectively in a team environment and to coordinate across the problem domain and solution domain; and
6. **Technical Leadership:** Skills and behaviors associated with the ability to guide a diverse team of experts toward a specific technical goal.

Proficiency areas 1 to 3 consist of primarily ‘hard’ or technically based skills, while proficiency areas 4 to 6 consist primarily of the ‘soft’ or interdisciplinary skills. Development and evaluation of soft skills is addressed by the disciplines of psychology, social sciences, and management sciences. The six proficiency areas in *Atlas* are further divided into categories and, in some cases, into topics, as shown in Table 12. Each of the proficiency areas is elaborated in the subsequent sections.

**Table 12. Atlas 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 and Statistics   |   |
|  | 1.4. Calculus and Analytical Geometry                                   |   |
|  | 1.5. Computing Fundamentals   |   |
| 2. Systems’ Domain & Operational Context | 2.1. Principal and Relevant Systems                                     | < List of Principal and Relevant Systems >  |
|  | 2.2. Familiarity with Principal System’s Concept of Operations (ConOps) |   |
|  | 2.3. Relevant Domains   | < List of relevant Domains >  |
|  | 2.4. Relevant Technologies  | < List of relevant Technologies >   |
|  | 2.5. Relevant Disciplines and Specialties                               | < List of relevant Disciplines and Specialties >  |
|  | 2.6. System Characteristics   | < List of applicable System Types, Scales, and Levels >   |
| 3. Systems Engineering Discipline        | 3.1. Lifecycle  | 3.1.1 Lifecycle Models<br>3.1.2 Concept Definition<br>3.1.3 System Definition<br>3.1.4 System Realization<br>3.1.5 System Deployment and Use<br>3.1.6 Product and Service Life Management |
|  | 3.2. Systems Engineering Management                                     | 3.2.1 Planning<br>3.2.2 Risk Management<br>3.2.3 Configuration Management<br>3.2.4 Assessment and Control<br>3.2.5 Quality Management   |

| Area                                  | Category  | Topic   |
|---------------------------------------|---|---|
|                                       | <b>3.3.</b> SE Methods, Processes, and Tools                    | <b>3.3.1</b> Balance and Optimization<br><b>3.3.2</b> Modeling and Simulation<br><b>3.3.3</b> Development Process<br><b>3.3.4</b> Systems Engineering Tools   |
|                                       | <b>3.4.</b> Systems Engineering Trends                          | <b>3.4.1</b> Complexity<br><b>3.4.2</b> Model Oriented Systems Engineering<br><b>3.4.3</b> Systems Engineering Analytics<br><b>3.4.4</b> Agile Systems Engineering  |
|                                       |   |   |
| <b>4.</b> Systems Engineering Mindset | <b>4.1.</b> Big-Picture Thinking                                |   |
|                                       | <b>4.2.</b> Paradoxical Mindset                                 | <b>4.2.1</b> Big-Picture Thinking and Attention to Detail<br><b>4.2.2</b> Strategic and Tactical<br><b>4.2.3</b> Analytic and Synthetic<br><b>4.2.4</b> Courageous and Humble<br><b>4.2.5</b> Methodical and Creative |
|                                       | <b>4.3.</b> Flexible Comfort Zone                               |   |
|                                       | <b>4.4.</b> Abstraction   |   |
|                                       | <b>4.5.</b> Foresight and Vision                                |   |
| <b>5.</b> Interpersonal Skills        | <b>5.1.</b> Communication                                       | <b>5.1.1</b> Audience<br><b>5.1.2</b> Content<br><b>5.1.3</b> Mode  |
|                                       | <b>5.2.</b> Listening and Comprehension                         |   |
|                                       | <b>5.3.</b> Working in a Team                                   |   |
|                                       | <b>5.4.</b> Influence, Persuasion and Negotiation               |   |
|                                       | <b>5.5.</b> Building a Social Network                           |   |
| <b>6.</b> Technical Leadership        | <b>6.1.</b> Building and Orchestrating a Diverse Team           |   |
|                                       | <b>6.2.</b> Balanced Decision Making & Rational Risk Taking     |   |
|                                       | <b>6.3.</b> Guiding Stakeholders with Diverse/Conflicting Needs |   |
|                                       | <b>6.4.</b> Conflict Resolution & Barrier Breaking              |   |
|                                       | <b>6.5.</b> Business and Project Management Skills              |   |
|                                       | <b>6.6.</b> Establishing Technical Strategies                   |   |
|                                       | <b>6.7.</b> Enabling Broad Portfolio-Level Outcomes             |   |
|                                       |   |   |

Throughout the remainder of this section, individuals with the highest proficiency self-assessments are individuals who reported attaining a “7 or higher” on a 10-point scale for their self-assessments. With the updated *Atlas* rubric, these would equate to individuals who rated themselves, “4/Advanced” or “5/Expert”).

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### 5.1.2. MATH/SCIENCE/GENERAL ENGINEERING

A good understanding of math, science, and general engineering is a critical foundation for effective systems engineers; but this understanding is largely ‘assumed’ in a systems engineer when joining the workforce since proficiency in this area is not utilized directly or in isolation. However, it is upon this foundation that further understanding of the categories under Proficiency Area 2: *Systems’ Domain & Operational Context* is built.

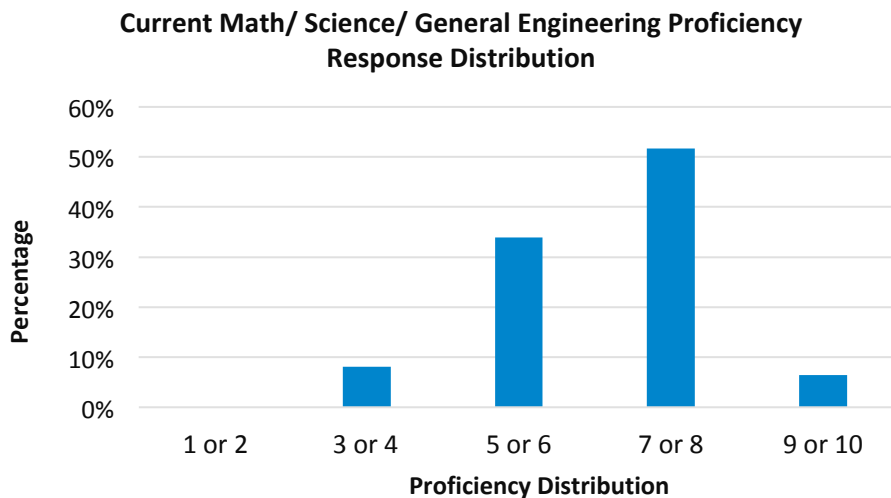
The *Graduate Reference Curriculum for Systems Engineering (GRCSE®)* defines the types of prerequisite knowledge individuals should have before entering a master’s program in systems engineering (Pyster et al. 2015). Since limited insight was obtained from Helix data collection and analysis for this proficiency area, GRCSE is used to identify and define the categories in this area:

- 1.1.Natural Science Foundations:** Basic concepts and principles of one of the natural science disciplines (e.g., physics, biology, chemistry, etc.); includes laboratory work that involves experimental techniques, the application of the scientific method, and comprehension of appropriate methods for data quality assurance and analysis.
- 1.2.Engineering Fundamentals:** The nature of engineering, branches of engineering, the design process, analysis and modeling, the role of empirical and statistical techniques, problem solving strategies, and the value of standards; some level of practical experience is expected, whether through capstones, internships, or course projects. Practical experience should include the application of engineering fundamentals in a specific domain context.
- 1.3.Probability and Statistics:** Basic probability theory, random variables and probability distributions, estimation theory, hypothesis testing, regression analysis, and analysis of variance.
- 1.4.Calculus and Analytical Geometry:** Theory and application of differential and integral calculus methods and operations; study of techniques for describing, representing, and analyzing geometric objects (coordinate systems, algebraic models, graphing).
- 1.5.Computing Fundamentals:** Overview of computer organization (computer architecture, operating systems, and programming languages), algorithms, and data structures; software engineering fundamentals (lifecycle models, quality, cost, and schedule issues); and development of a software unit (design, coding, and testing).

Proficiencies in Area 1: Math/Science/General Engineering may be considered as the general foundation that is provided in any undergraduate engineering degree. Advanced levels of these

topics are included in the topics of Area 2, in the context of the system of concern. For an individual without a formal undergraduate degree in engineering, obtaining the proficiencies in Area 1 could happen through experience, training, or mentoring.

As it can be observed in Figure 42, more than half of systems engineers identified their Math/Science/General Engineering skills to be “between 7 and 8”. Again, this is on the previous 10-point scale; this translates to “4/Advanced” to “5/Expert” in the updated rubric. None of the participants graded themselves with a grade of 1 or 2 (which equates to “1/Novice” in the new rubric).

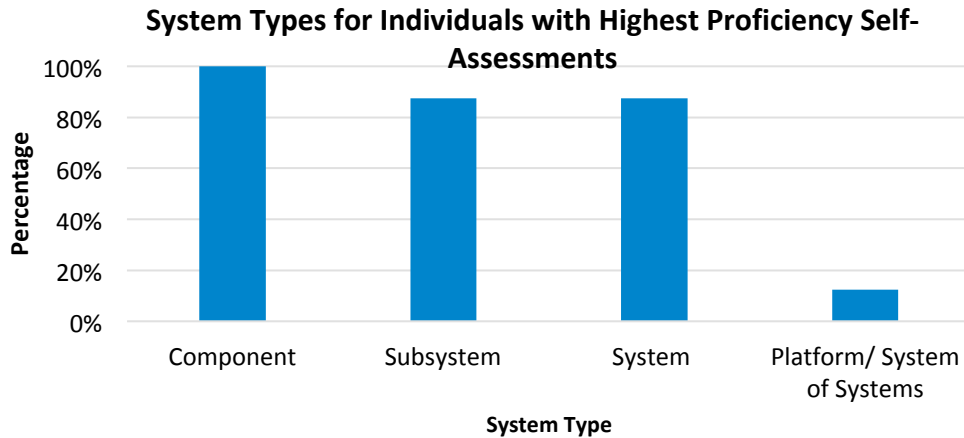


**Figure 41. Proficiency Distribution for Math/Science/General Engineering**

Next, the team uses information of the most popular responses (7 or 8) to provide an example of what proficiency patterns might be discovered. Information from individuals who self-graded with a 7 or an 8 was retrieved to examine for patterns in terms of, systems type, organization type and roles.

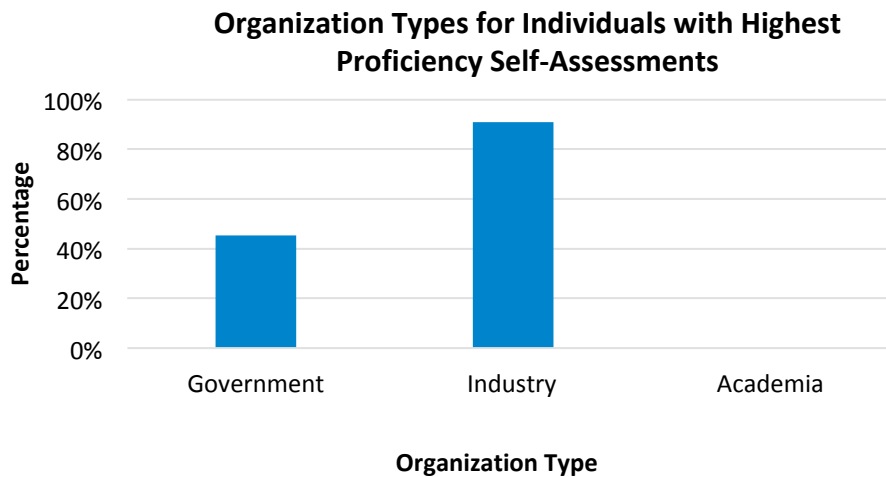
Figure 42 illustrates that all systems engineers who responded 7 or 8 to the Math/Science/General Engineering proficiency model have been exposed to the component level. Also, more than three-quarters of those participants are exposed to the subsystem and system. Only 14% of those interviewed have been exposed to the Platform/Systems of System type of system.





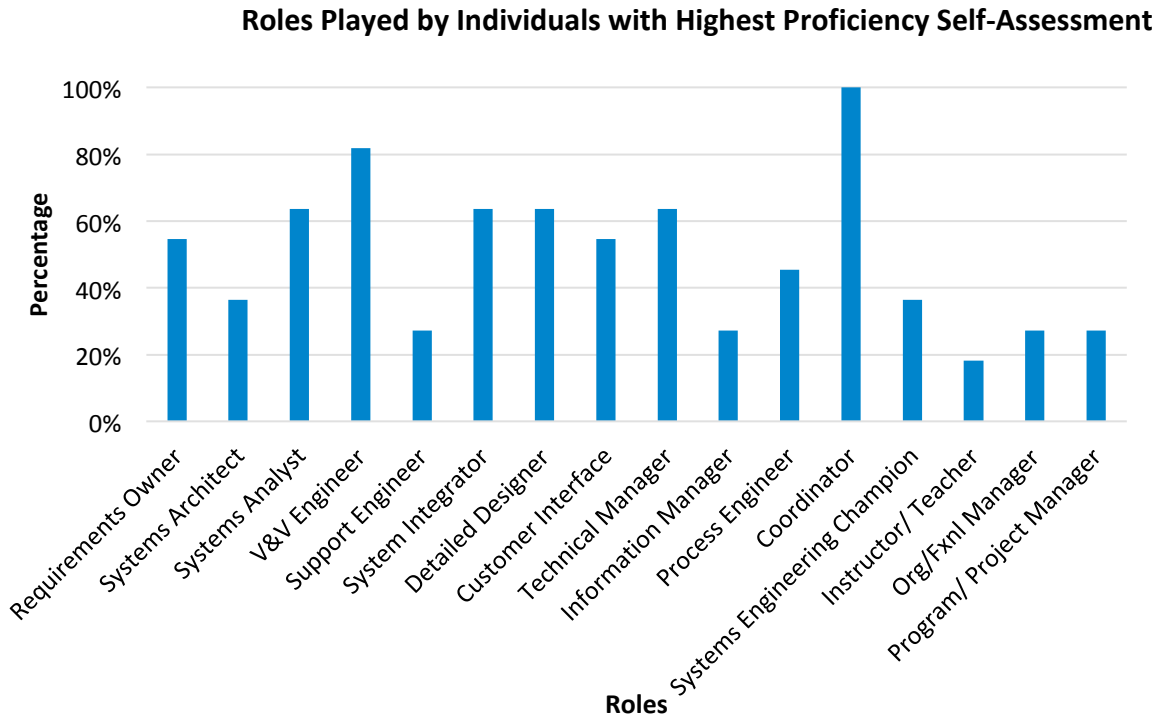
**Figure 42. Distribution for individuals with highest proficiency self-assessment in Math/Science/General Engineering**

In regard to the type of organization, 91% of engineers who responded 7 or 8 to Math/Science/General Engineering have experience in the industry. Less than half of participants (45%) have been involved in government-type of organizations while no-systems engineer have Academic experience. Figure 43 illustrates the organization type for those participants who answer 7 or 8.



**Figure 43. Distribution for organization types for individuals with the highest proficiency self-assessments in Math/Science/General Engineering**

Figure 44 denotes the most frequent roles for individuals who graded themselves 7 or 8. As it can be observed, all participants played the role of coordinator. Verification and Validation is the second most frequent role while Instructor or Teacher is the least common role.



**Figure 44. Roles distribution for individuals with highest proficiency self-assessments in Math/Science/General Engineering**

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### 5.1.3. SYSTEM’S DOMAIN & OPERATIONAL CONTEXT

The second proficiency area is *System’s Domain & Operational Context*, which contains the relevant domains, technologies, disciplines, specialties, and characteristics for a given system, and the operation of that system. This proficiency area strongly corresponds to the organization and the systems that its systems engineers work on. If an individual transitions to a new system either, the proficiency level may change depending on familiarity with the new relevant domains, technologies, and disciplines. The categories for this proficiency area are defined below:

**2.1.Principal and Relevant Systems:** *Principal* systems are those systems that are of primary interest to the organization. High levels of proficiency in those specific systems are desired by the organization. If a combat ship were the principal system, relevant systems could be submarines and aircraft carriers, which are types of combat ships.

**2.2.Familiarity with Principal System’s Concept of Operations (ConOps):** A system’s concept of operations (ConOps) of how systems in the domain are used and deliver value, especially those systems on which the individual personally works. Familiarity with the principal system’s ConOps is of particular interest, though familiarity with the ConOps of other related systems may also be helpful.

**2.3.Relevant Domains:** *Domain* refers to the overarching area of application of the system;

this includes things such as space, aerospace, marine, communication, finance, etc. Proficiency in related domains outside the primary one may enable an individual to be more effective in the primary domain. For example, experience in space systems may enable a systems engineer to work in aerospace systems more readily than an engineer who is proficient primarily in finance systems.

**2.4.Relevant Technologies:** Within the context of a system, there are specific technologies that are relevant. For example, on a marine system, these may be technologies such as gas turbine, radar, and sonar systems; and each technology has its own terminology, challenges, etc.

**2.5.Relevant Disciplines and Specialties:** Disciplines are fundamental areas of education or expertise that are foundational to a system. For example, for a communications system, electrical engineering will be an important discipline to understand, while civil engineering will be less relevant. Specialties are disciplines that support systems engineering by applying cross-cutting knowledge. Specialties include Reliability, Availability, and Maintainability (RAM), Human Systems Integration, Safety Engineering, Affordability and other related topics.

**2.6.System Characteristics:** Three characteristics are considered in *Atlas*:

- **System Type:** Types of systems include technical systems, social systems, human systems, physical systems, cyber systems, and any combination of these. Another classification of system types includes product systems, service systems, and enterprise systems.
- **System Scale:** Systems can be anywhere from a nano level to a distributed global or enterprise level. A generic systems engineering development process may be applicable to systems at any scale.
- **System Scope:** What can be seen as a system from one perspective, could be a subsystem from another perspective. The levels of a system could range from component/element, subsystem, system, and platform or system of systems.

Category 2.6 is a change from older versions of *Atlas*. In previous versions, there was a category called “System Complexity” under Proficiency Area 3 (Systems Engineering Discipline). However, as the Helix team worked with organizations that were implementing, questions arose about other systems aspects in the proficiency model. For example, there was a concern that system complexity was identified but not the scope of a system nor different system scopes from element to system of systems. The Helix team agreed that though these were covered in the experiences of systems engineers, this was a gap in the existing proficiency model. After reviewing discussions on proficiency from the data, the team determined that several characteristics should be called out. Because these were related to the types of systems, the team determined that the new category, “System Characteristics”, was a better fit in Proficiency Area 2 (System’s Domain and Operational Context).

Note that this refers to the ability of an individual to work effectively on systems with different characteristics. This is related to, but distinct from, experiences an individual has on these types

of systems.

As it can be observed in Figure 45, more than half of systems engineers identified their Domain & Operational Context skills to be between 7 and 8. None of the participants graded themselves with a grade of 1 or 2 or the grades 3 or 4.

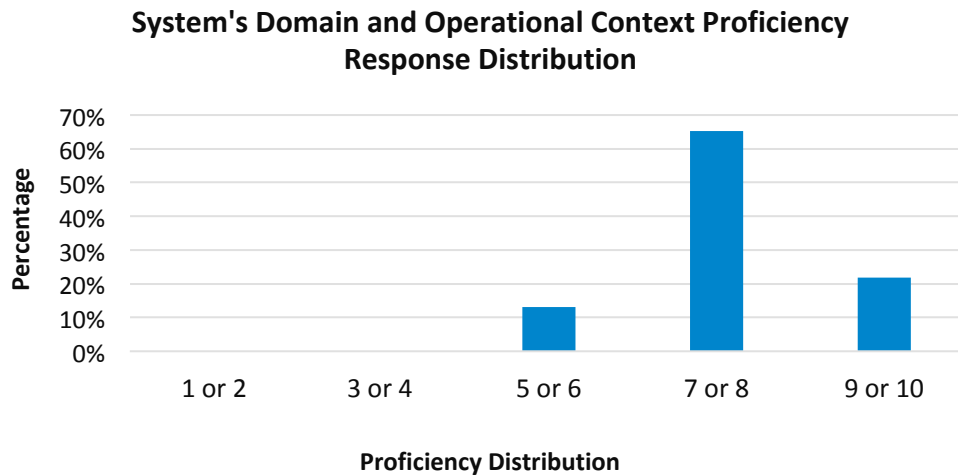


Figure 45. Proficiency distribution for System's Domain and Operational Proficiency responses

Figure 46 illustrates that more than three-quarters of systems engineers who responded 7 or 8 to the Domain and Operational Context proficiency model have been exposed to the component, subsystem and system level. Also, only 10% of those interviewed have been exposed to the Platform/Systems of System type of system.

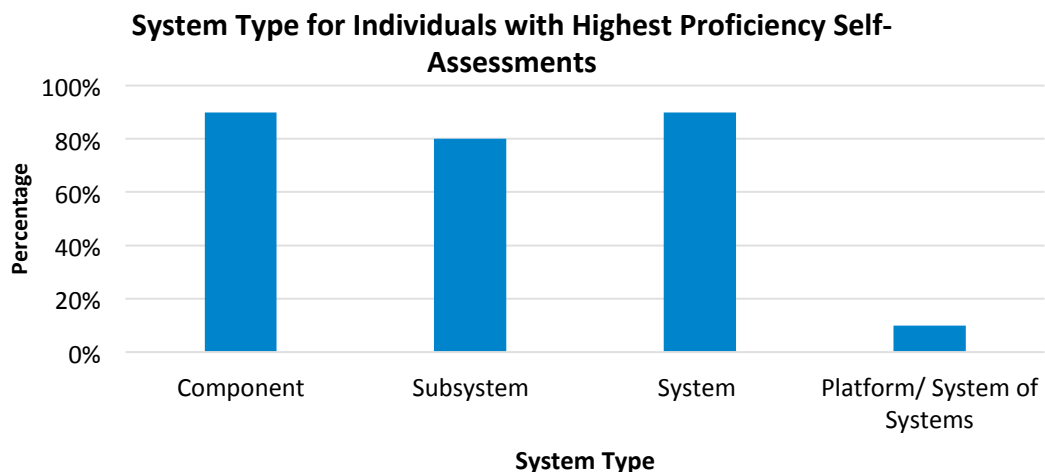
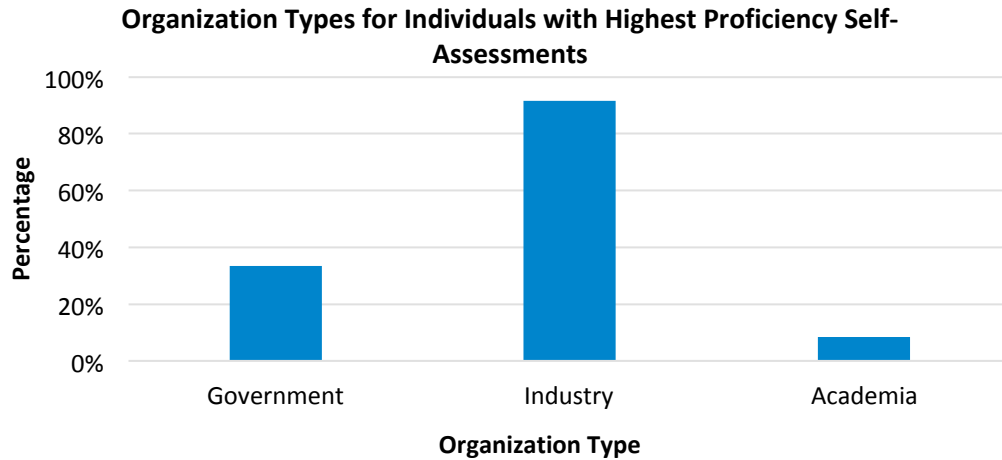


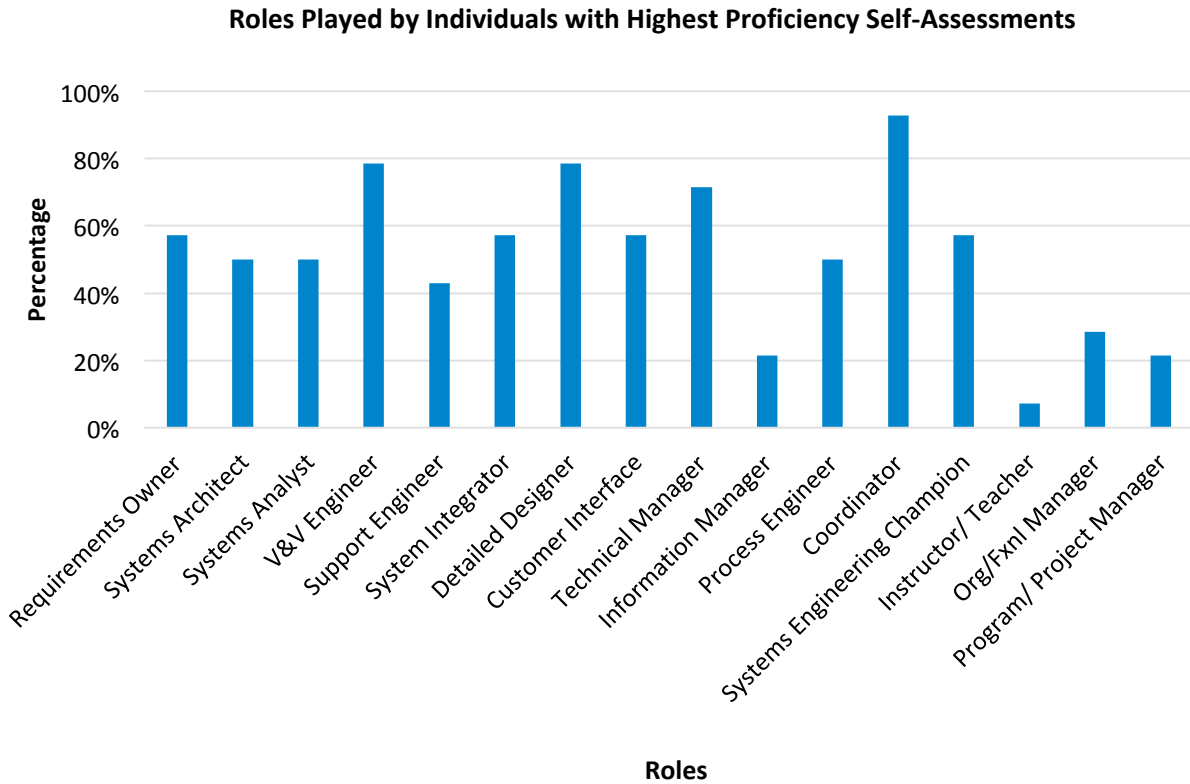
Figure 46. Distribution for system types of individuals with the highest proficiency self-assessments in System's Domain and Operational Context

In regard to the type of organization, 92% of engineers who responded 7 or 8 to System’s Domain and Operational Context have experience in the industry. One in three participants (33%) have been involved in government while only 8% have Academic experience. Figure 47 illustrates the organization type for those participants who answer 7 or 8.



**Figure 47. Distribution for organization types for individuals with the highest proficiency self-assessments in System’s Domain and Operational Context**

Figure 48 denotes the most frequent roles for individuals who graded themselves 7 or 8. As it can be observed, most participants played the role of Coordinator. Verification and Validation (79%) as well as Detailed Designer (79%) are the second most frequent roles. The least played role is Instructor or Teacher with only (7%).



**Figure 48. Roles distribution for individuals with the highest proficiency self-assessments in System’s Domain and Operational Context**

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#### 5.1.4. SYSTEMS ENGINEERING DISCIPLINE

The third proficiency area is *Systems Engineering Discipline*. The categories below were developed based on data from Helix interviews about critical systems engineering knowledge and skills. The names of the categories come from the *Guide to the Systems Engineering Body of Knowledge (SEBoK)* (BKCASE Editorial Board 2016). Some of the categories are further expanded into topics.

**3.1.Lifecycle:** *The organized collection of activities, relationships and contracts that apply to a system-of-interest during its life* (Pyster 2009). This is a roll up of knowledge about lifecycles and proficiency in specific aspects of the lifecycle. Topics 3.1.2 – 3.1.6 below, represent generic lifecycle phases in system development:

**3.1.1. Lifecycle Models:** *A framework of processes and activities concerned with the lifecycle that may be organized into stages, which also acts as a common reference for communication and understanding* (ISO/IEC/IEEE 15288). Lifecycle Models include Vee model; iterative models such as the spiral development model; formal acquisition models (e.g., as defined in DoD 5000.2 2013); or less formal acquisition models (e.g., quick reaction capability or internal research and

development (IR&D) models).

**3.1.2. Concept Definition:** *A set of core technical activities of systems engineering in which the problem space and the needs of the stakeholders are closely examined* (BKCASE Editorial Board 2016). This consists of analysis of the problem space, business or mission analysis, and the definition of stakeholder needs for required services.

**3.1.3. System Definition:** *A set of core technical activities of systems engineering, including the activities that are completed primarily in the front-end portion of the system design.* (BKCASE Editorial Board 2016) This consists of the definition of system requirements, the design of one or more logical and physical architectures, and analysis and selection between possible solution options.

**3.1.4. System Realization:** *The activities required to build a system, integrate disparate system elements, and ensure that a system both meets the needs of stakeholders and aligns with the requirements identified in the system definition stage* (BKCASE Editorial Board 2016). This includes implementation as well as integration, verification, and validation (IV&V).

**3.1.5. System Deployment and Use:** *A set of core technical activities of systems engineering to ensure that the developed system is operationally acceptable and that the responsibility for the effective, efficient, and safe operations of the system is transferred to the owner* (BKCASE Editorial Board 2016). Considerations for deployment and use must be included throughout the system lifecycle. Activities within this phase include deployment, operation, maintenance, and logistics.

**3.1.6. Product and Service Life Management:** Deals with the overall lifecycle planning and support of a system (BKCASE Editorial Board 2016). The life of a product or service often spans a considerably longer period of time than the time required to design and develop the system. This stage includes service life extension, updates, upgrades, and modernization, and disposal and retirement.

**3.2. Systems Engineering Management:** *Managing the resources and assets allocated to perform systems engineering, often in the context of a project or a service, but sometimes in the context of a less well-defined activity. Systems engineering management is distinguished from general project management by its focus on the technical or engineering aspects of a project* (BKCASE Editorial Board 2016). The topics contained in the *Systems Engineering Management* category are defined below:

**3.2.1. Planning:** Planning involves developing and integrating technical plans to achieve the technical project objectives within the resource constraints and risk thresholds. This involves the success-critical stakeholders to ensure that necessary tasks are defined with the right timing in the lifecycle in order to manage acceptable risks levels, meet schedules, and avoid costly omissions (BKCASE Editorial Board 2016).

**3.2.2. Risk Management:** Organized, analytic process to identify what might cause harm or loss (identify risks); to assess and quantify the identified risks; and to develop and, if needed, implement an appropriate approach to prevent or handle causes of risk that could result in significant harm or loss (ISO/IEC/IEEE 24765:2010 – SEVocab).

**3.2.3. Configuration Management:** A discipline applying technical and administrative direction and surveillance to: identify and document the functional and physical characteristics of a configuration item, control changes to those characteristics, record and report change processing and implementation status, and verify compliance with specified requirements (ISO/IEC/IEEE 24765:2010 – SEVocab).

**3.2.4. Assessment and Control:** This process involves determining and initiating the appropriate handling strategies and actions for findings and/or discrepancies that are uncovered in the enterprise, infrastructure, or lifecycle activities associated with the project (BKCASE Editorial Board 2016).

**3.2.5. Quality Management:** Whether a systems engineer delivers a product, a service, or an enterprise, the deliverable should meet the needs of the customer and be fit for use. Such a deliverable is said to be of high quality. The process to assure high quality is called quality management (BKCASE Editorial Board 2016).

**3.3.SE Methods, Processes, and Tools:** *A systems engineering method is set of activities, methods, practices, and transformations that people use to develop and maintain systems and associated products* (SEI 2007). Processes generally refer to the specific guidelines an organization develops for implementing systems engineering methods; tools refer to software programs that are designed to support systems engineering activities. The topics contained in the *SE Methods, Processes, and Tools* category are outlined below:

**3.3.1. Balance and Optimization:** Specialty engineers often focus on the details and optimization of their specific components of the system, but that optimization of individual components often leads to a less-than-optimal system solution. Systems engineers, therefore, have to be able to balance the desire for component optimization with the optimization for the system overall, which often requires sub-optimization for one or more components.

**3.3.2. Modeling and Simulation:** *A model is a simplified representation of a system at some particular point in time or space intended to promote understanding of the real system. A simulation is the manipulation of a model in such a way that it operates on time or space to compress it, thus enabling one to perceive the interactions that would not otherwise be apparent because of their separation in time or space* (Bellinger 2004). This topic represents an individual's ability to understand and perform modeling and simulation; this understanding is more fundamental than the ability to use software tools that support modeling and simulation.

**3.3.3. Development Processes:** Each organization has its own processes that govern the



development of systems. It is important for systems engineers to understand generic systems engineering processes, but also the specific processes being used for development within the organization or domain.

**3.3.4. Systems Engineering Tools:** Systems engineers need to be able to utilize tools to support overall system development and to perform the systems engineering development process. Tools may include requirements management and other tools that assist with project life management (PLM).

**3.4. Systems Engineering Trends:** *Current and future trends in performing Systems Engineering, that modify the way systems are developed.*

**3.4.1. Complexity:** Complexity of a system is generally understood to exist not in a higher order scale or level of a system, but rather in the higher order of interactions between system elements, disciplines, or technologies, and the properties that emerge out of these interactions that are not present in the individual elements. One categorization of complexity includes structural complexity, dynamic complexity, and socio-political complexity; while another identifies two kinds of complexity: disorganized complexity and organized complexity (SEBoK authors 2016).

**3.4.2. Model Oriented Systems Engineering:** Model Based Systems Engineering (MBSE) is a theme that is being increasingly adopted in systems engineering, where models are used to describe various elements of systems and the systems development process. Model Oriented Systems Engineering (MOSE) goes beyond MBSE, and presents a holistic model-based approach that integrates operational, technical, programmatic and business dimensions as well.

**3.4.3. Systems Engineering Analytics:** The increasing ability to collect, store, analyze, and gain insights from large quantities of data has significantly improved the area of analytics in general. This perspective can also be applied to systems engineering, where complex phenomena within systems and systems development can be measured and analyzed.

**3.4.4. Agile Systems Engineering:** The shrinking of systems engineering development lifecycles, increasingly uncertain and rapidly changing requirements and operational environments of modern systems, has led to the development and adoption of agile systems engineering approaches.

The Helix team determined that as these are specific applications of systems engineering, they fit within Proficiency Area 3; the Helix team has labeled these “trends”. Rather than selecting a single trend, the Helix team determined that creating a category for “Systems Engineering Trends” was more reasonable than creating categories for each potential trend. The trends listed in 3.4 are consistent with some of the areas of interest expressed across a number of organizations in the Helix sample. Additional trends could be added as they become more prominent in the systems engineering community.

Figure 49 illustrates the distribution for Systems Engineering Discipline responses. As it can be observed more than half of systems engineers identified their Systems Engineering Discipline skills to be between 7 and 8. Also, one in four systems engineers believe their skills are between 9 and 10. None of the participants believe that their skills are underdeveloped since none graded himself with a grade of 1 or 2.

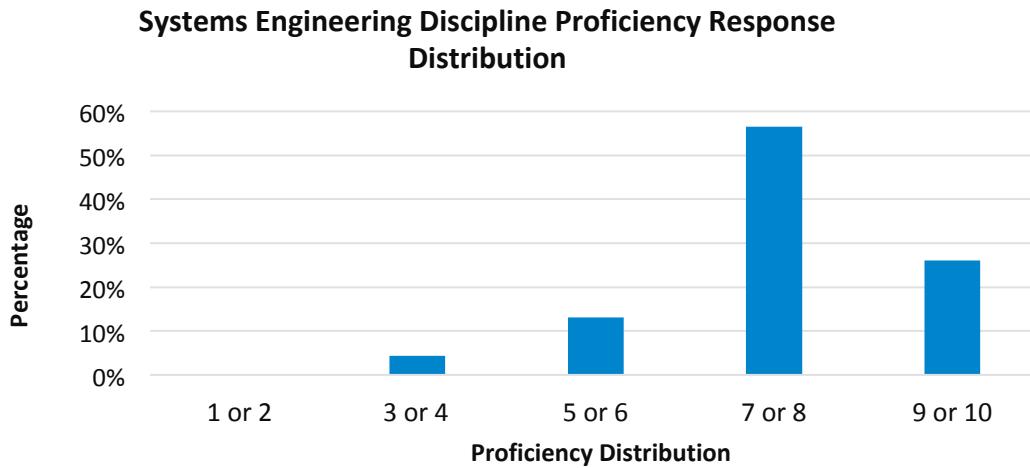


Figure 49. Proficiency distribution for Systems Engineering Discipline responses

Figure 50 illustrates that more than three-quarters of systems engineers who responded 7 or 8 to the Systems Engineering Discipline proficiency model have been exposed to the component and system level. Also, only 67% of participants have been exposed to the subsystem level. Lastly, 17% of those interviewed have been exposed to the Platform/Systems of System type of system.

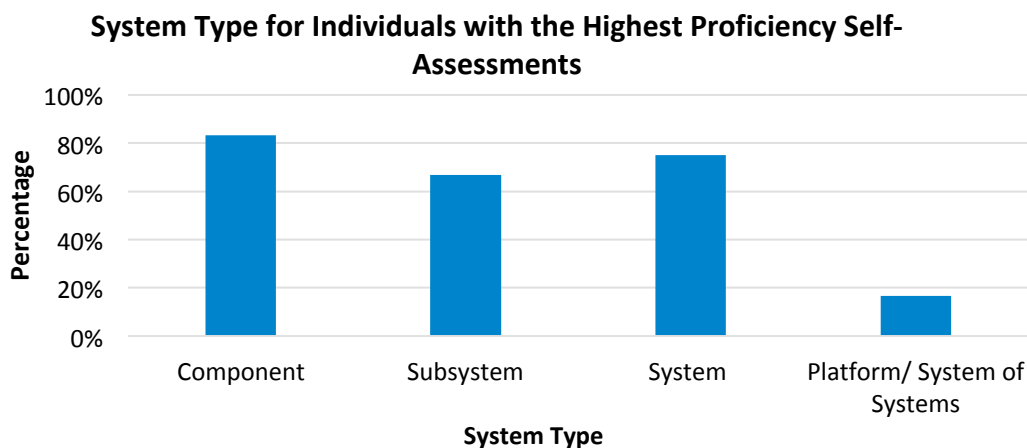


Figure 50. Distribution for system types for individuals with the highest proficiency self-assessments in Systems Engineering Discipline

In regard to the type of organization, 92% of engineers who responded 7 or 8 to Domain and Operational Context have experience in the industry. One in four participants (25%) have been involved in government of organizations. Also, 17% of participants have Academic experience. Figure 51 illustrates the organization type for those participants who answer 7 or 8.

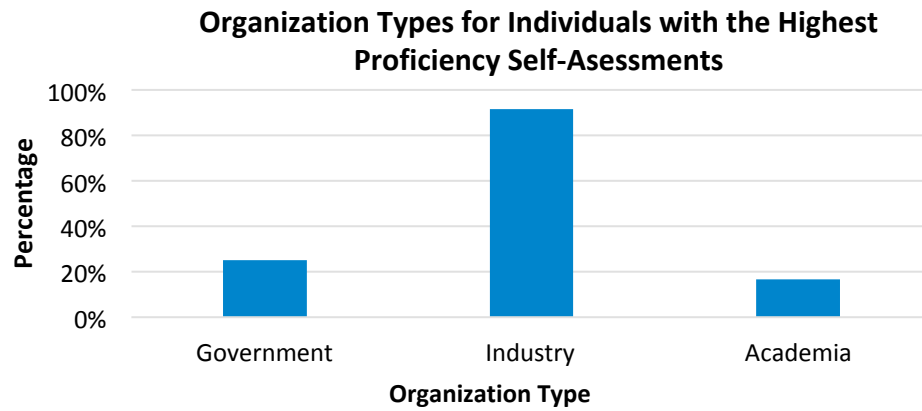


Figure 51. Distribution for organization types for individuals with the highest proficiency self-assessments in Systems Engineering Discipline

Figure 52 denotes the most frequent roles for individuals who graded themselves 7 or 8. As it can be observed, most participants played the role of Coordinator (93%). Verification and Validation (79%) as well as Detailed Designer (79%) are the second most frequent roles. The least played role is Instructor or Teacher with only (14%).

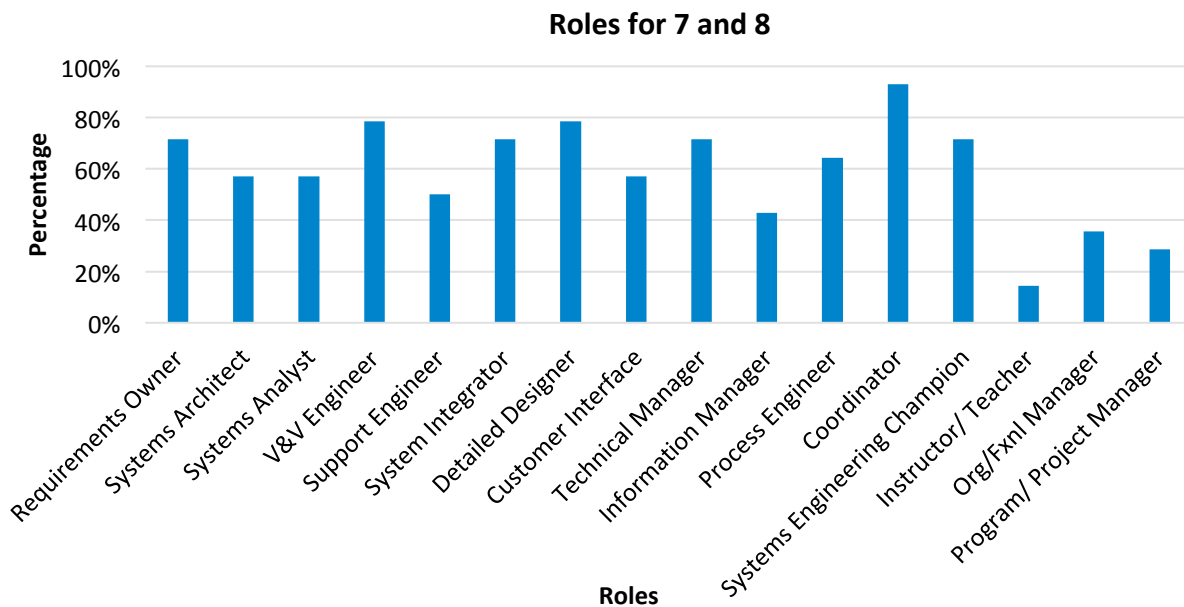


Figure 52. Roles distribution for individuals with the highest proficiency self-assessments in Systems Engineering Discipline

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### 5.1.5. SYSTEMS MINDSET

The fourth proficiency area is *Systems Mindset*, which is primarily focused on patterns of thinking, perceiving, and approaching a task that are particularly relevant to systems engineers. The categories included in this area are:

**4.1. Big-Picture Thinking:** Also referred to as ‘systems thinking’ and ‘holistic thinking’, this includes the ability to step back and take a broader view of the problem at hand; this is an important and essential characteristic of systems engineers. ‘Big-picture’ could refer to a broader perspective along many different dimensions: the system as a whole including interfaces and integration, and not limited to any sub-system or component; the system while in operation, and its interactions with other systems and the operating environment; the entire lifecycle of the system, and not limited to the current stage of the system; the development program in the context of the organization and all its other development programs; the end goal or solution to the problem at hand; the perspectives of different stakeholders; and the technical as well as business perspectives. A systems engineer is usually *the* person to bring this broader perspective, while classic engineers and subject matter experts often tend to be narrowly focused on their area of interest. Systems engineers are not only called to provide this big-picture perspective themselves, but to also enable others to see this bigger picture.

**4.2. Paradoxical Mindset:** *The ability to hold and balance seemingly opposed views, and being able to move from one perspective to another appropriately.* Typically, an engineer may hold one view or the other, but rarely *both*. By having this paradoxical mindset, a systems engineer contributes value that is not usually expected from others. The opposing-concept pairs are:

**4.2.1. Big-Picture Thinking and Attention to Detail:** Big-picture thinking provides the broader higher-level perspective; at the same time, a systems engineer is also required to pay attention to the details of how things work and how they come together in a system.

**4.2.2. Strategic and Tactical:** Systems engineers need to be strategic, focused on the end result of ‘vision’ for the system, but also need to handle the tactical day-to-day activities and decisions required to reach that vision. They must also be able to appreciate “how what is done today is going to affect things downstream”. A related concept pair is the ability to envision long-term issues but at the same time, have the desire for closure with the current situation in order to move on.

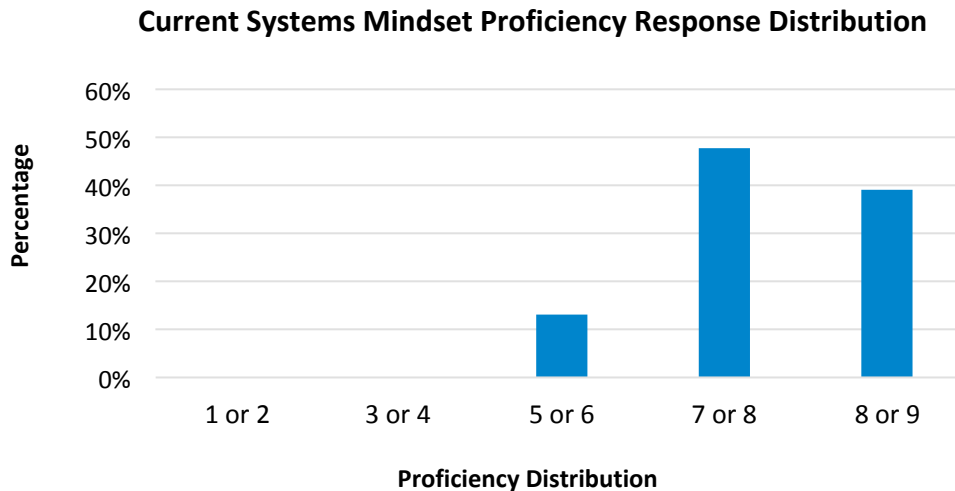
**4.2.3. Analytic and Synthetic:** A big-picture perspective may be associated with the ability to be synthetic, and to be able to bring together and integrate different pieces of a puzzle. However, a systems engineer also needs to be analytic and to be able to break down the big picture into smaller pieces on which others can focus and work. To do this effectively, a systems engineer needs to be able to operate at multiple levels (e.g., component, sub-system, system, system-of-systems) and multiple dimensions (e.g., various technical disciplines and stakeholder perspectives).

**4.3.Adaptability:** *The overall ability to deal with ambiguity and uncertainty, this involves the abilities to be open-minded, understand multiple disciplines, deal with challenges, and the ability to take rational risks.* By definition, experts possess proficiency in a specific area, which is their ‘comfort zone’; and they typically do not prefer going outside that circle or comfort zone. Such experts provide value to the organization by contributing their expertise in those focused areas. However, systems engineers tend to show an ability to broaden their comfort zones, and go beyond their current boundaries and they are also comfortable doing this.

**4.4.Abstraction:** *The ability to filter out and understand the critical bits of information at the right level and to make relevant inferences.* And even with that filtered information, systems engineers need to know when to use or not use pieces of information. Such abstraction also enables systems engineers to connect and extract meaning from different streams of information; for example, to tie together information that subject matter experts of two different disciplines are providing.

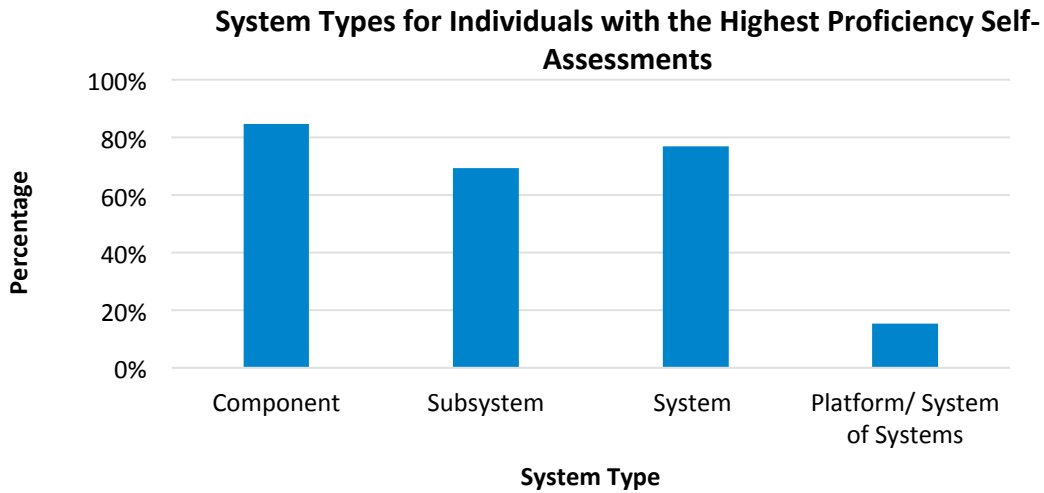
**4.5.Foresight and Vision:** *The ability to foresee the remaining lifecycle of the system, the impact of current decisions, and to mentally simulate possible scenarios.* Every decision or change is likely to have an impact beyond the current confines of time or space. Particularly in early stages of a system lifecycle, and in the development of a new or unfamiliar system, foresight is a key value that systems engineers provide.

Figure 53 illustrates the distribution for Systems Engineering Mindset responses. As it can be observed slightly less than half (48%) of systems engineers identified their Systems Engineering Mindset skills to be between 7 and 8. Also, more than one in three (39%) systems engineers believe their skills are between 9 and 10. None of the participants believe that their skills are underdeveloped since none graded himself with a grade of 1 or 2 or the range 3 or 4.



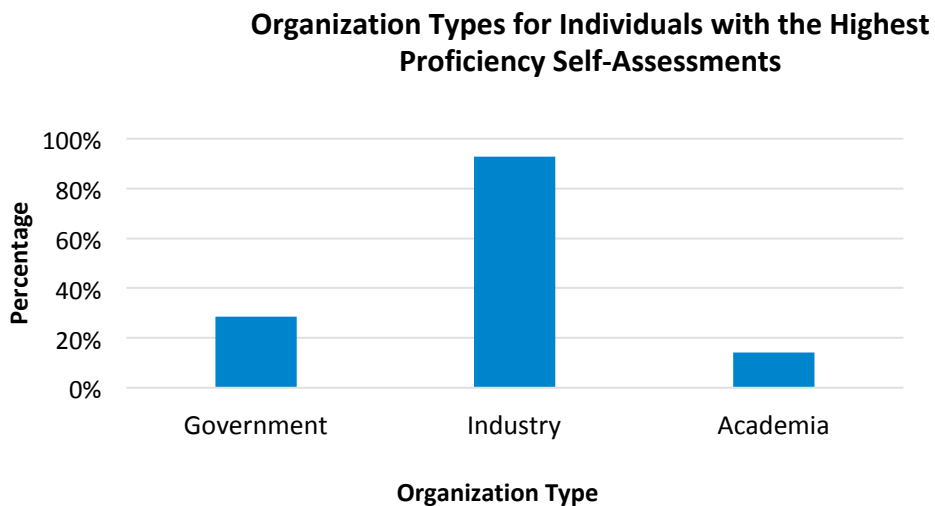
**Figure 53. Proficiency distribution for Systems Engineering Mindset responses**

Figure 54 illustrates that more than three-quarters of systems engineers who responded 7 or 8 to the Systems Engineering Mindset proficiency model have been exposed to the component and system level. Also, only 69% of participants have been exposed to the subsystem level. Lastly, 15 % of those interviewed have been exposed to the Platform/Systems of System type of system.



**Figure 54. Distribution for system types for individuals with the highest proficiency self-assessments in Systems Mindset**

Figure 55 illustrates the organization type for those participants who answer 7 or 8. 93% of engineers have experience in the industry. Less than 30% are experienced in government organizations while only 14% have been exposed to academia



**Figure 55. Distribution for organization types for individuals with the highest proficiency self-assessments in Systems Mindset**

Figure 56 denotes the most frequent roles for individuals who graded themselves 7 or 8. As it can be observed, all participants played the role of Coordinator. Verification and Validation (81%) is the second most frequent role. Detailed Designer (75%) and Technical Manager (75%) are both the third most popular role. The least played role is Instructor or Teacher with only (19%).

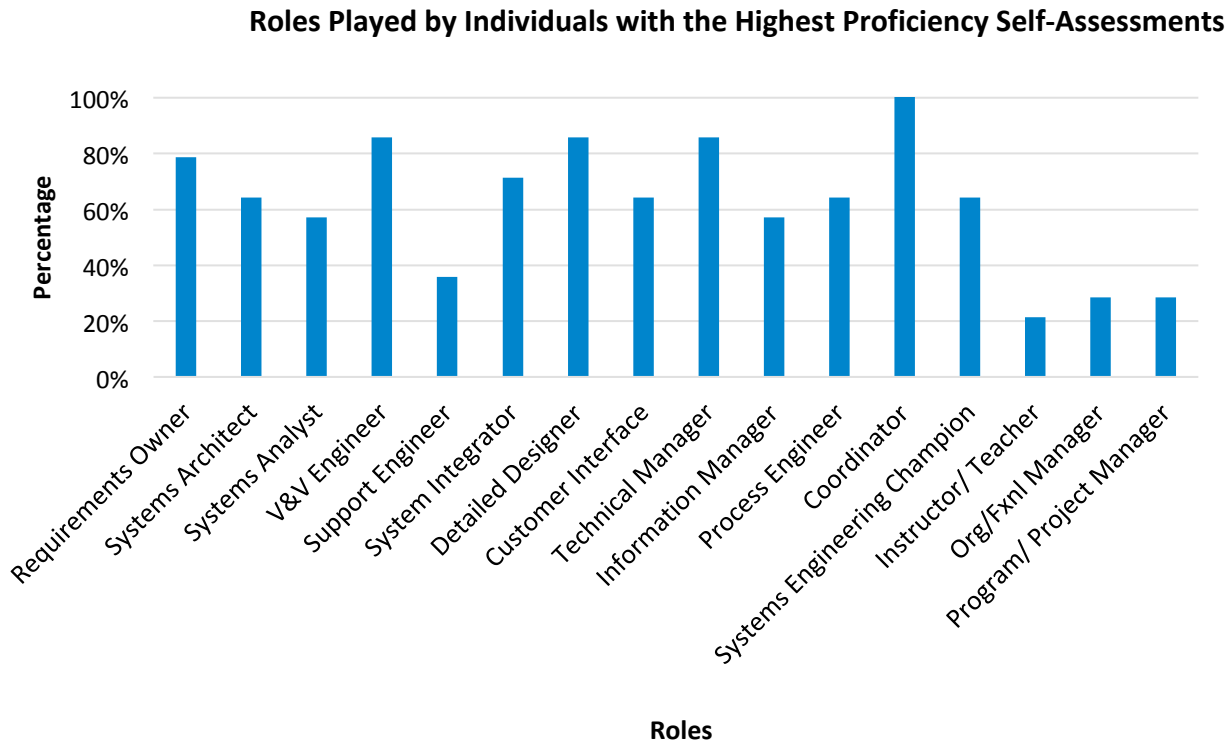


Figure 56. Roles distribution for individuals with the highest proficiency self-assessments in Systems Mindset

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### 5.1.6. INTERPERSONAL SKILLS

The fifth proficiency area is *Interpersonal Skills*. Almost by definition, systems engineers do not just work by themselves at their desks all day – they interact with people. Irrespective of any formal leadership roles they may or may not play, a systems engineer is expected to be proficient in a number of interpersonal skills. While specialty engineers may be responsible for developing specific aspects of the system, systems engineers are responsible for coordinating across all of these engineers. Hence, interpersonal skills are more critical to systems engineers than they are to specialty engineers. The specific categories contained within this proficiency area are listed below:

**5.1.Communication:** Communication is critical for systems engineers since they interact with a variety of people, and is a broad category covering a wide variety of related skills and abilities. Often they are an important link between individuals and groups, both internal and external to the organization – most importantly, the customers and end-

users of the system being developed. Systems engineers need the ability to clearly express their thoughts and perspectives to establish a shared common understanding.

**5.1.1. Audience:** Systems engineers need to communicate with a variety of direct and indirect audiences: customers; subject matter experts; program managers; vice presidents; directors; specialty engineers; problem owners; technical teams; contractors; decision makers; system testers; and others working on or with the project.

**5.1.2. Content:** The variety of content that systems engineers need to communicate can be broadly divided into three types, based on the audience they are communicating with:

1. **Technical:** Communications with disciplinary and specialty engineers and subject matter experts involve high technical content. But communications of technical issues to managers, end-users, and others who may not be interested in or who may be confused by all the technical detail, involves adequate abstraction of the technical content.
2. **Managerial:** Systems engineers often provide project status to managers and supervisors and cost-schedule constraints and expectations to technical personnel.
3. **Social:** Systems engineers need to maintain an amicable environment within a team and to interact with others in a courteous manner. Such interactions involve communications that are neither technical nor managerial in nature.

**5.1.3. Mode:** Communicating the intended content to the target audience is done through a number of different modes:

1. **Oral:** This takes various forms, depending on the audience and context. It could be one-on-one, or as part of a team, in person, or remotely.
2. **Presentation:** A special form of communications is the ability to stand in front of an audience and to deliver a presentation using appropriate aids. Further, during presentations, systems engineers tend to represent others who may not be in the room: they present customer needs and requirements to others in the absence of customers, and they present design decisions and system related issues to customers in the absence of designers.
3. **Writing and Documentation:** Written communication skills are equally critical for systems engineers; the scale, audience, and objective of the written artifact also matter. It could range from a short email to communicate status, to a detailed test plan, to internal documentation supporting a project decision, to design documents being submitted for review.

**5.2. Listening and Comprehension:** The ability to listen to others' points of views and



perspectives, and to comprehend and internalize the message accurately. For systems engineers, listening begins with the customer to understand their real needs and ensure that these needs get translated into requirements. In a team environment, systems engineers need to listen to the views and perspectives being offered: from designers, subject matter experts, and others.

**5.3.Working in a Team:** Systems engineers tend to be part of many teams during the lifecycle of the system; further, systems engineering by itself is typically not performed by an individual, but rather by a team. Hence, team dynamics and synergy are key to the functioning of a systems engineer.

**5.4.Influence, Persuasion, and Negotiation:** It is critical for every systems engineer, not just those in formal leadership positions, to have the skills needed to make a point and to successfully obtain buy-in. In many situations, systems engineers contribute a perspective that is different from that of others: a focus on the overall system and on customer’s needs. In such situations, it requires influence, persuasion, and negotiating skills for systems engineers to enable others to see the bigger picture on which they need to focus.

**5.5.Building a Social Network:** A systems engineer needs to be a ‘people person’, and build a social network of professional acquaintances. Such a network becomes a valuable resource for systems engineers to tap into, because they are not expected to know answers to all problems, but rather be able to find someone who has the expertise and ability to solve the problem.

Figure 57 illustrates the distribution for Interpersonal Skills responses. As it can be observed 74% of systems engineers identified their Interpersonal skills to be between 7 and 8. Also, participants who graded themselves between 5 or 6 and 9 or 10 are distributed evenly with 13% each category. None of the participants believe that their skills are underdeveloped since none graded himself with a grade of 1 or 2 or the range 3 or 4.

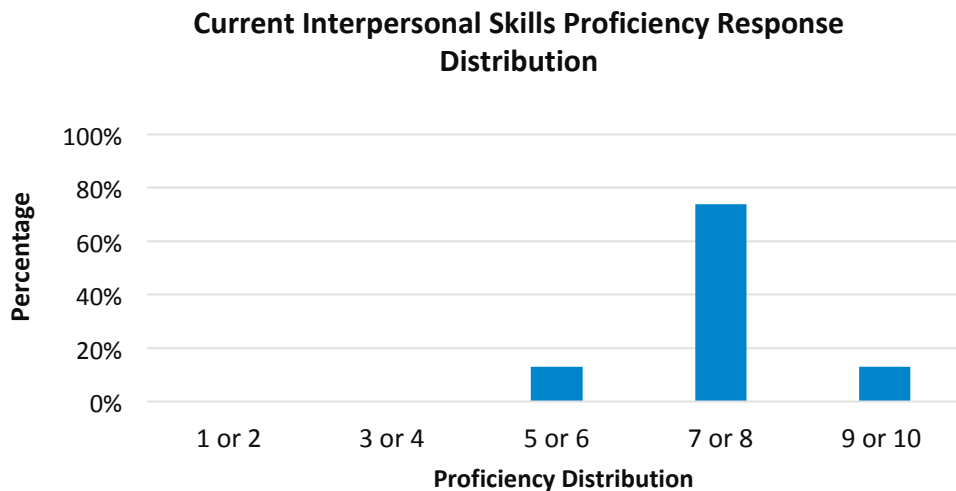


Figure 57. Proficiency distribution for Interpersonal Skills responses

Figure 58 illustrates that 93% of systems engineers who responded 7 or 8 to the Interpersonal Skills proficiency model have been exposed to the component level. Exposure to the subsystem and system level has been distributed evenly both with 80% of the total number of participants. Lastly, 20 % of those interviewed have been exposed to the Platform/Systems of System type of system.

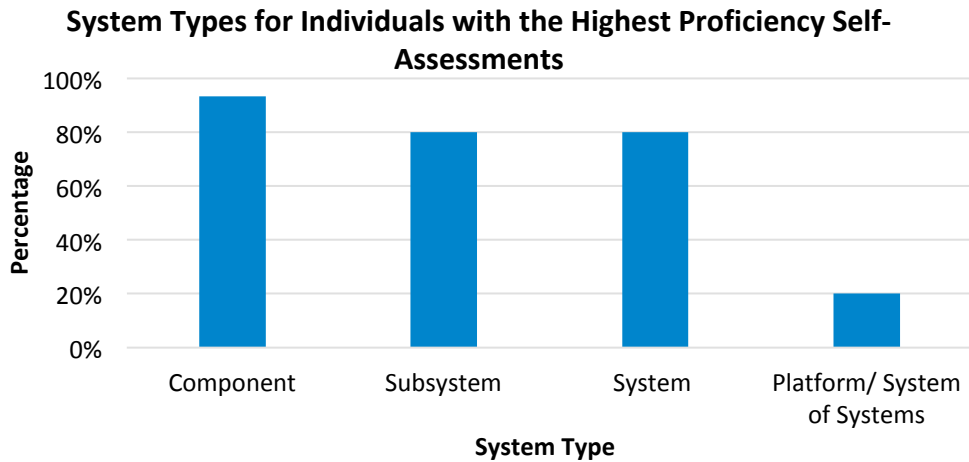


Figure 58. Distribution for system types for individuals with the highest proficiency self-assessments in Interpersonal Skills

Figure 59 illustrates the organization type for those participants who answer 7 or 8. 88% of engineers have experience in the industry. Also, 35% are experienced in government organizations while only 6% have been exposed to academia.

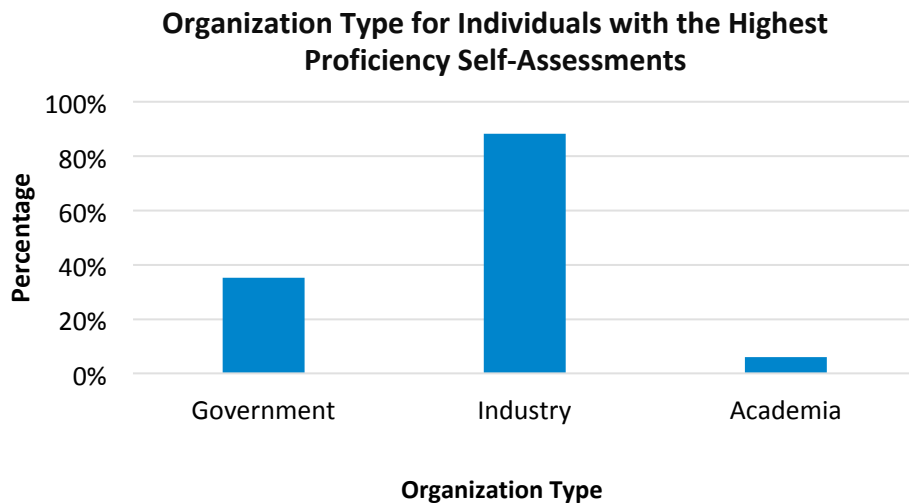


Figure 59. Distribution for organization types for individuals with the highest proficiency self-assessments in Interpersonal Skills

Figure 60 denotes the most frequent roles for individuals who graded themselves 7 or 8. As it can be observed, all participants played the role of Coordinator. Requirements Owner, Verification and Validation and Technical Manager are the second most played roles with (82%)The least played role is Instructor or Teacher with only (18%).

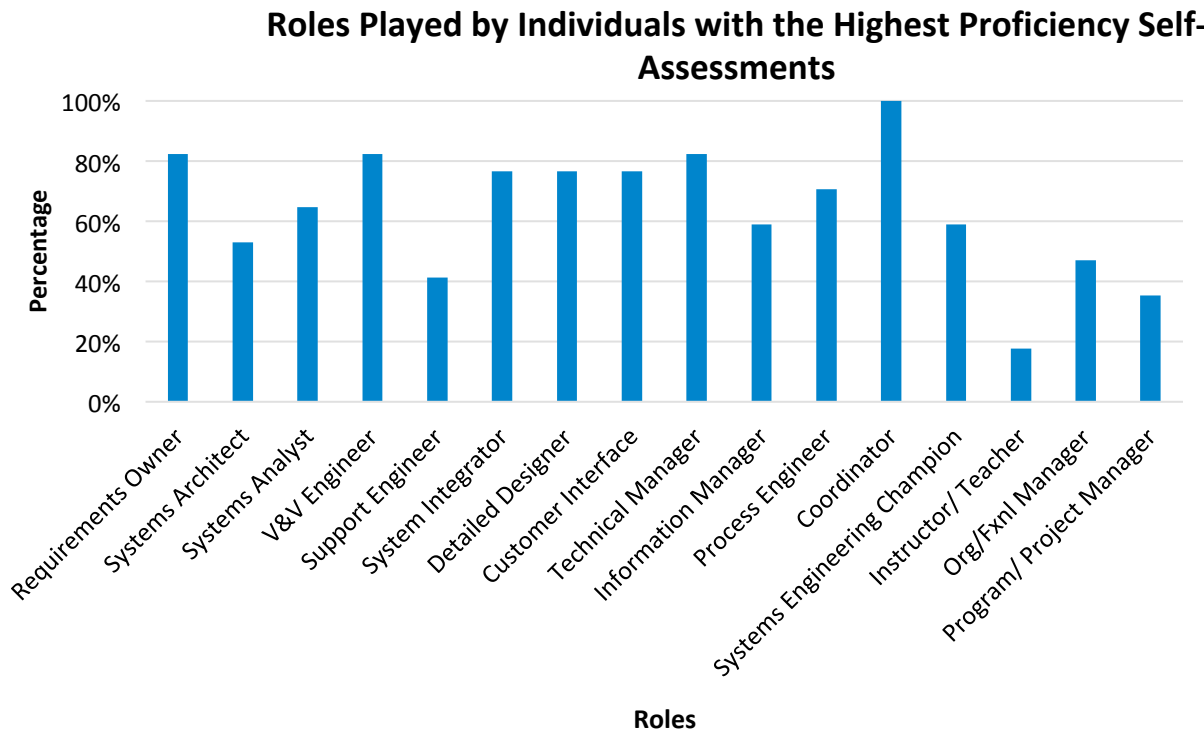


Figure 60. Roles distribution for individuals with the highest proficiency self-assessments in Interpersonal Skills

### 5.1.7. TECHNICAL LEADERSHIP

The sixth and final *Atlas* proficiency area is *Technical Leadership*. It is common and natural for systems engineers to play leadership roles at many levels within an organization. The specific categories contained within *Technical Leadership* are listed below:

**6.1. Building and Orchestrating a Diverse Team:** *The ability to identify, build, and effectively guide or coach a team comprising individuals with diverse expertise, perspectives, and personalities.* While organizational titles may vary, it is most often a systems engineer who is the leader of the team that is charged with delivering the system. The systems engineer needs to fully know each of the team members: their strengths, weaknesses, capacities, capabilities, limitations, personalities, expertise, and working styles. The systems engineer plays the roles of coach, guide, and teacher to develop the team’s capabilities and to orchestrate it to perform the required tasks. Individual leadership styles could vary, but the overall objective of is to empower the team, to instill

confidence, and to help them to deliver the solution and to be successful. Another key aspect of handling a team is the ability to delegate – the leader needs to build enough trust in the team to be able to delegate with confidence.

**6.2.Balanced Decision Making and Rational Risk Taking:** Solving a problem requires a systems engineer to take a number of balanced decisions considering a variety of factors, constraints, perspectives, and objectives; as well as the implications of these decisions and their scope of impact. An additional challenge is that most often, all the required information may not be readily available. The ability to make such decisions also requires the systems engineer to be comfortable in dealing with ambiguity and uncertainty and to be able to take rational, calculated risks.

**6.3.Guiding Diverse Stakeholders:** This includes the ability to manage all the internal and external stakeholders, and to keep the team focused on their needs, especially those of the end user or customer. The systems engineer is uniquely positioned to interact with many stakeholders of the system – both external and internal to the organization. Being this “touch point” person, the systems engineer needs to deal with multiple personalities, behaviors, organizations, and cultures.

**6.4.Conflict Resolution and Barrier Breaking:** Conflicts are bound to rise in a variety of scenarios – within the team; within the organization – between the technical side and business side of the organization; as well as with outside the organization. As a leader, the systems engineer must resolve these conflicts while keeping the system goals in mind. In some cases, conflicts arise due to the existence of barriers, which may be related to the organizational culture, processes, team personalities, or other situations that could prevent an individual or team from getting their work done. The systems engineer needs the ability to break these barriers.

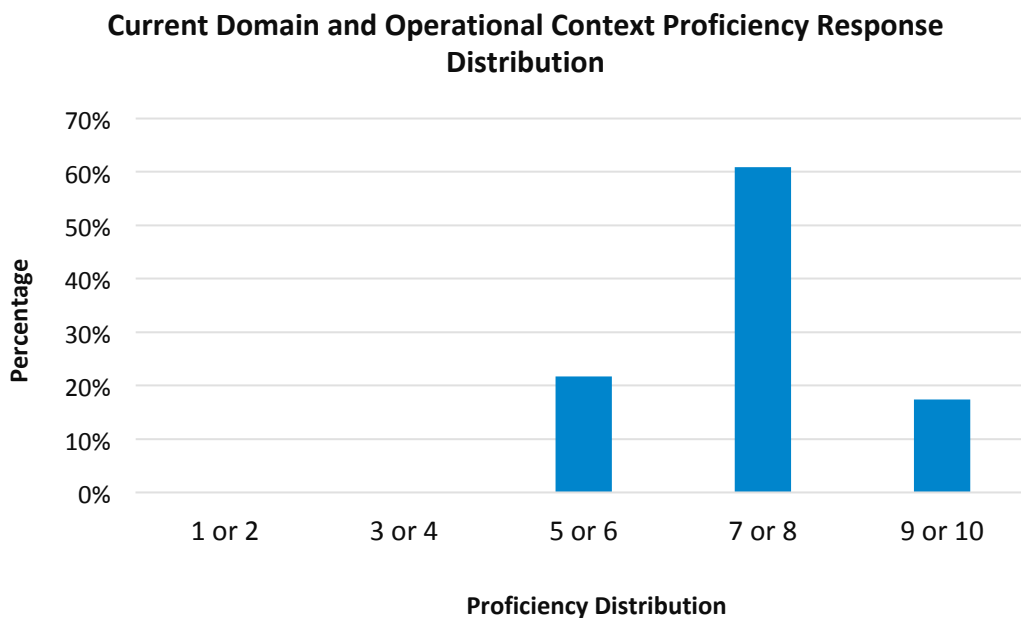
**6.5.Business and Project Management:** Depending on the way roles and titles are defined within an organization, a systems engineer’s responsibilities may overlap with what may be seen as ‘project management’ responsibilities. Even if there is no overlap, a systems engineer is expected to handle a variety of business and project management activities including accounting, budget, cost estimation, schedule, work breakdown, and profit. The systems engineer must also be cognizant of the business impact of technical decisions that are taken.

**6.6.Establishing Technical Strategies:** Systems engineers must fearlessly and creatively guide the establishment of new capabilities and transformations (e.g., to migrate to Cloud Infrastructure, or to establish a new information service architecture, or to enable transition to a DEVOPS model). Senior systems engineers need to be able to support the organization in the development of overarching technical directions and support the development of technical roadmaps that establish a vision to support the strategy.

**6.7.Enabling Broad Portfolio-Level Outcomes:** Along with the development of strategies to guide strategic technical investments, systems engineers should provide the broad perspective necessary to enable technical success not only on individual projects but across projects and programs to enable advancement across the technical portfolio.

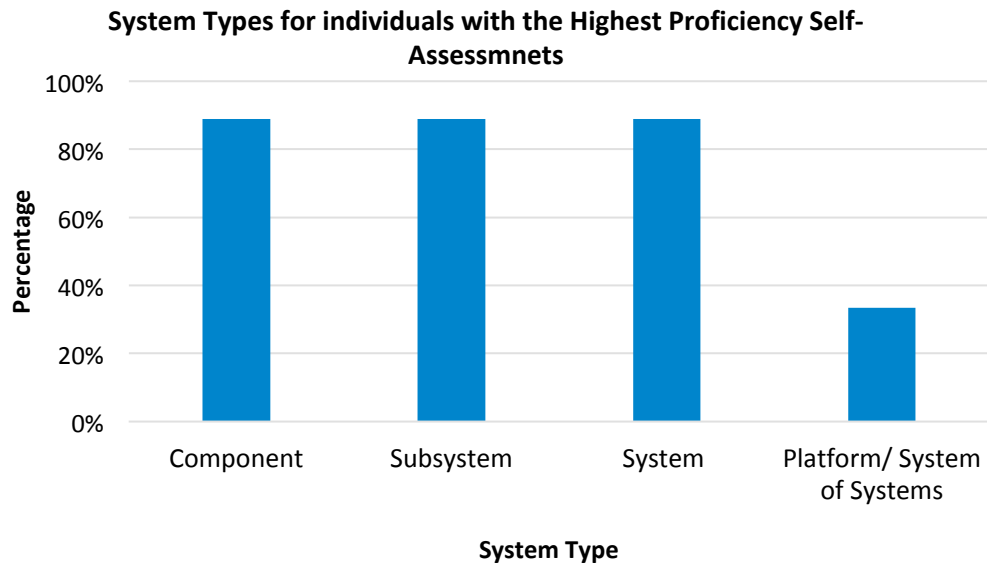
Note that Categories 6.6 and 6.7 are new to *Atlas 1.0*. These categories speak not just to technical leadership within teams, but also to technical leadership within an organization. These were not initially included because they were heard clearly at few organizations in the Helix sample. However, the Helix team hopes that *Atlas* will be relevant not only today but in the future. To this end, community outreach, implementation work, and literature review in 2016 has focused on ensuring that the proficiency model will be relevant for future systems engineers as well. Categories 6.6 and 6.7 speak to a vision of roles that systems engineers should play in future (e.g. INCOSE *Vision 2025*, 2014) and aligns with proficiencies already expected of senior systems engineers in some organizations.

Figure 61 illustrates the distribution for Systems Engineering Mindset responses. As it can be (60%) of systems engineers identified their Technical Leadership skills to be between 7 and 8. Also, 21% stated that their personal skills are ranked between 5 or 6. 17% systems engineers believe their skills are between 9 and 10. None of the participants believe that their skills are underdeveloped since none graded himself with a grade of 1 or 2 or the range 3 or 4.



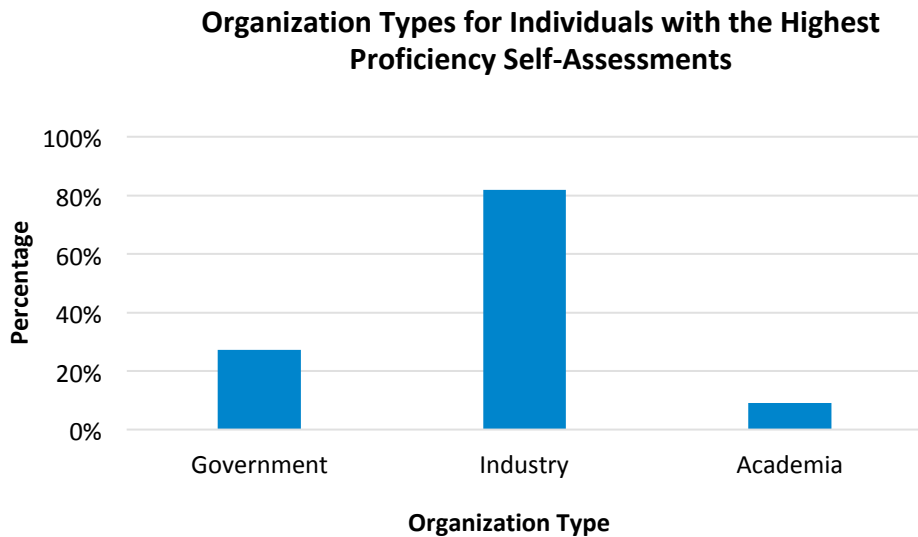
**Figure 61. Proficiency distribution for Technical Leadership**

Figure 62 illustrates that more than three-quarters of systems engineers who responded 7 or 8 to the Technical Leadership proficiency model have been exposed to the component and system level. Also, 33% Platform/Systems of System type of system.



**Figure 62. Distribution for system types for individuals with the highest proficiency self-assessments in Technical Leadership**

Figure 63 illustrates the organization type for those participants who answer 7 or 8. 82% of engineers have experience in the industry and 27% are experienced in government organizations while only 9% have been exposed to academia



**Figure 63. Distribution for organization types for individuals with the highest proficiency self-assessments in Technical Leadership**

Figure 64 denotes the most frequent roles for individuals who graded themselves 7 or 8. As it can be observed, all participants played the role of Coordinator. Detailed Designer (91%) is the second most frequent role. Requirements Owner, Verification and Validation, Customer

Interface and Technical Manager all occupy the third position with (73%). The least played role is Instructor or Teacher with only (18%).

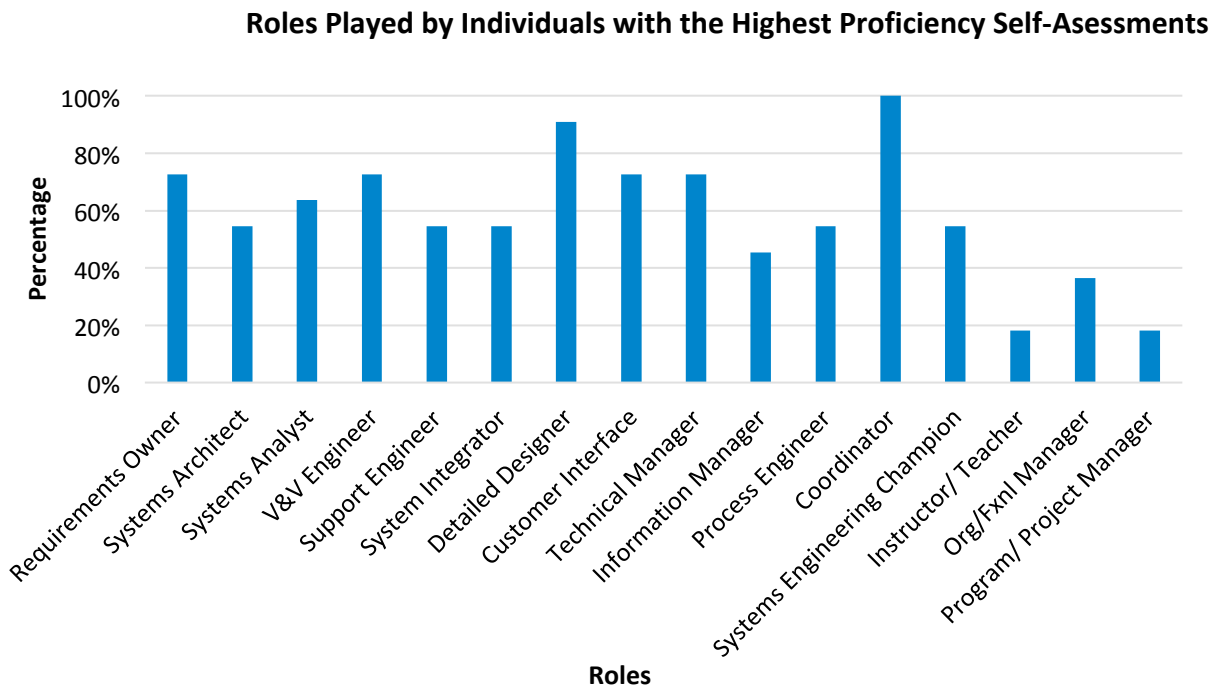


Figure 64. Roles distribution for individuals with the highest proficiency self-assessments in Technical Leadership

## 6. ANSWERING FREQUENTLY ASKED QUESTIONS ABOUT CAREER PATHS

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Whenever *Atlas* is presented to the community, there are several questions that frequently are asked about career paths. Though many of these are answered in the “Interpreting the Results” sections above, the Helix team provides brief answers here for those who prefer a briefer summary. Each section references the appropriate analyses; readers are encouraged to review the details if they have questions.

Did we answer your questions? If not, please contact the Helix team at [helix@stevens.edu](mailto:helix@stevens.edu).

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### 6.1. SE PRACTITIONERS: DOES IT MATTER HOW I MOVE THROUGH THE SYSTEM LIFECYCLE?

The Helix team gets this question frequently and often, members of the community will share their opinions on this quite vehemently. The truth, though, is that despite examining the career paths of 178 systems engineers, no one clear path or even handful of paths emerged as the “right” way to move through the systems lifecycle. Section 3.2.1 provides detailed analysis of the ways systems engineers in the sample have moved through the lifecycle; Section 4.2.1 for chief systems engineers (CSEs) in the sample.

The most commonly-recommended ways to move through the lifecycle from senior systems engineers interviewed were from “front-to-back” or “back-to-front”. The idea was that either way would allow an individual to experience the full lifecycle and particularly highlight the relationships between the lifecycle stages. However, almost none of the systems engineers in the Helix dataset actually moved through the lifecycle in these exact ways.

Here is the bottom line of the analysis on lifecycle stages:

- **Variety is important.** In terms of growth, there are no CSEs in the sample that have experiences in fewer than four lifecycle stages. It was stated repeatedly throughout the Helix interviews that someone must see most of the lifecycle to grow as a systems engineer. The specific order, based on the data available, appears less important than the variety.
- **Abstraction is critical.** Part of what moving through the systems engineering lifecycle does for systems engineers is it helps them identify patterns and points of integration between the different lifecycle phases. The more effective systems engineers are better at identifying these patterns – or abstracting patterns from their experiences – in a way that can inform them for new experiences.



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## 6.2. SE PRACTITIONERS: HOW CAN I FIGURE OUT IF I AM DOING THE RIGHT THINGS?

Another common question both in the Helix interviews and when Helix is presented publicly is, “Am I doing the right things to grow as a systems engineer?” It is an astute question that illustrates these individual’s desire for improved self-awareness (a critical enabling personality characteristic).

As with many questions in the systems engineering world, the answer to this question is, “It depends.” It depends on how you are looking to grow and what your targeted end state is and it depends on when you are hoping to reach this state. An individual with a career path exposing them to two phases of the lifecycle and only three systems engineering roles may be doing exactly the right things to move from a junior systems engineer focused on requirements to a mid-level systems engineer focused on analysis in the next three years. However, if that same individual is targeting a position as a CSE in the next three years, then he or she would be decidedly off track.

The key questions you must ask yourself to answer this question are:

- **What is it I am hoping to achieve?** What is the position you want to grow into? If not a specific position, what are the areas where you are hoping to grow? If you can not answer these questions, then “on track” has little meaning.
- **What is your career path now?** This document provides an overview of career path analysis and the companion *Atlas 1.1 Implementation Guide* provides considerably more detail on how to create your own career path assessment and target states for proficiencies. Without the understanding of where you are now and how you go here, it is impossible to determine whether or not you are on an appropriate path for growth.
- **How does your career path compare to that of others?** Sections 3 and 4 of this document provide a number of patterns against which an individual can begin this analysis. Other good approaches are to discuss this with your supervisor or mentor – who can help you by providing their own insights into your career path – or if you have a specific target position in mind, talk with individuals in that position and find the gaps between what they did to get there and what you have already done.

Perhaps the most important step of this is not just to know “where you are” but also to have a plan on getting to where you want to go. (See 6.3 below)

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## 6.3. SE PRACTITIONERS: HOW DO I FIGURE OUT WHAT I SHOULD DO NEXT?

As with Question 6.2, a critical aspect of answering this question is asking yourself where you want to go. For some, this is actually the hardest part of figuring out where to go next. Usually within your current organization, you can find a manager, supervisor, mentor, or senior systems

engineer who can help you understand what is possible within your organization. Knowing what is possible outside your organization is a little more difficult, but the patterns highlighted in Sections 3 and 4 of this guide might give you some useful indicators.

Once you have done the hard work of determining where you want to go – and have hopefully done a gap analysis of that compared to where you are now (see Question 6.2) – you have a sense of what needs to change to enable you to grow. The question then becomes, “What is the right way to address this?”

In Section 5, there are many patterns highlighted for individuals who grew in terms of particular proficiencies, which can be very useful here. For example, if you have identified that you want to grow in “Systems Mindset”, for example, you can compare what you have done now with the career paths of individuals in the sample who had the highest self-assessments of proficiency in this area. Look at the patterns in terms of roles, lifecycle exposure, etc. If you notice that there roles commonly played by these individuals that you have never played, that is an indicator that you should seek opportunities to play these roles. Likewise for the other career patterns analyzed, such as education and training.

Note that this does not guarantee you success, but in general systems engineers in the Helix sample reported that when in doubt, adding diversity to your experiences can not be a problem.

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#### 6.4. SE LEADERS: HOW DO I USE THIS DATA TO HELP MY CURRENT SYSTEMS ENGINEERS?

Every leader of systems engineers the Helix team has worked with wants to know the answer to this question. They are proud of the work and abilities of their systems engineering workforce – but always aware that they can get better at what they do. Leaders want to know how to do this.

There are several ways that *Atlas* can help with this:

- **Assessing where your workforce is.** Some organizations already have a sense of this as they have internal competency models and methods for evaluation that impact those. But for most organizations in the Helix dataset, leaders had qualitative insights into this but no data to support it. Using the *Atlas* tools to assess how systems engineers are doing in terms of their roles and proficiencies is important. (See the *Atlas 1.1 Implementation Guide* for specific guidance on how to do this.)
- **Assessing where your organization is.** Just as important as knowing the skills and abilities of the workforce itself is assessing the context in which the organization works. *Atlas* assesses a number of variables in this area, from specifics such as how the organization defines systems engineering and rewards systems engineers, to the specific training and educational programs to support systems engineers, to more general

factors such as organizational culture. One of the most consistent findings in the Helix project is that an organization can have the most skilled workforce in the world, but if the organizational environment is not supportive of systems engineering, they will struggle to be effective. Understanding where your organization stands is critical an understanding what you can do to help.

- **Identifying the roadblocks.** With the results of the assessments described above, your organization should have enough information to begin identifying areas of concern. Perhaps there are proficiency areas in which the workforce overall tends to be less proficient than desire. Perhaps there are systems engineering roles identified in *Atlas* that are not performed in your organization. Or perhaps you realize that the way you award employees is antithetical to good systems engineering. (This has been the case in several organizations.) Whatever the issues, having identified them gives you a place to start.

For some issues, *Atlas* can only take you so far. If you have identified major cultural issues, consulting an organizational physiologist is likely a better move than poring over the Helix data. But if, for example, one of the issues is that systems engineers are frustrated because they have no clear guidance on career paths or are not aware of training opportunities, these are areas where the course ahead is relatively clear. The Helix data can provide additional insights in these and other areas. See the *Atlas 1.1 Implementation Guide* for specifics.

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## 6.5. SE LEADERS: HOW DO I USE THIS DATA TO IDENTIFY NEW SYSTEMS ENGINEERS?

This is a great question, and one the Helix team hears frequently. For this, examining the career paths of self-identified systems engineers is less helpful than turning to the interview data. One exception, though, is to note patterns in certain undergraduate programs that were frequently reported as being a “good background” for growing individuals fresh out of undergrad into systems engineers. The two that were heard most frequently were aerospace engineering and biomedical engineering. In both instances, the focus on engineering around a particular type of system meant that individuals were exposed to several classic engineering disciplines as well as integration concerns and how system characteristics such as weight or power consumption could impact the overall system. These degrees provided not only a background in the application area (aligning with *System’s Domain and Operational Context*) but also primed the individuals for Big-Picture Thinking.

Outside of educational indicators, systems engineering leaders, managers, and mentors reported looking for some specific indicators when trying to identify systems engineers:

- **Big Picture Thinking.** The main indicators described for this included asking “why” questions and demonstrating interest in and understanding of interfaces, whether technical or interpersonal. This can also be an indicator for Inquisitiveness (a personal enabling characteristic).

- **Communication Skills.** In particular, the ability to “translate” between different stakeholders such as engineers from different disciplines or engineers and management team members.
- **Self-aware individuals who are self-starters.** These are personal enabling characteristics identified in *Atlas* as better enabling systems engineers to grow. Individuals who are capable of taking initiative and working independently are particularly important as systems engineers are often in leadership positions. Self-awareness is critical, particularly in terms of enabling systems engineers to identify when they need to consult SMEs.

There were no “hard and fast” rules for identifying systems engineers, but the above reflect common patterns from a number of individuals in the Helix sample.

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#### **6.6. SE LEADERS: HOW DO I USE THIS DATA TO BUILD MY FUTURE SYSTEMS ENGINEERING WORKFORCE?**

The techniques for this are the same ones as identified in Question 6.4 above. The difference here is that an organization needs to assess not for current skills but against a target of what is needed in the future. When the Helix team asked systems engineering leaders what the future of systems engineering would hold, there often was hesitation. Things like model-based systems engineering or agile systems engineering were stated – but many organizations seemed to struggle with what they would really mean in their context and how they would be applied.

The *Atlas 1.1 Implementation Guide* provides some insights on how to plan for the future but does not help an organization define *what* future state of systems engineering it desires.

## 7. CONCLUSIONS

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Of the 363 individuals interviewed for Helix, 100% agreed that experiences were the most critical Force for growing systems engineers. Experiences, combined with the additional Forces of Mentoring and Education & Training, make up the career paths of systems engineers.

This *Guidebook* provides a career path extraction methodology based on statistical and text mining principles to be used by systems engineering organizations, systems engineering leaders, and practitioners to identify overarching career patterns in the field of systems engineering. Specific career patterns aim at facilitating systems engineering leaders with confidence when identifying new or potential systems engineers for projects.

In particular, this *Guidebook* provides information on patterns in career paths, including findings in terms of education, experiences, and organizations; frequently asked questions about career paths, which synthesizes statistical findings reported elsewhere in this report; and insights on relating career paths to proficiency and project performance. It also describes the relationship between proficiency and project performance.

There are more findings throughout the Guidebook than can be singularly summarized here. However, with respect to the patterns in the careers of Chief Systems Engineers (CSEs):

- Each CSE in the sample had a bachelor's degree; for 18%, this was the highest degree attained, which is about half the rate in the larger Helix sample. Over 8% of CSEs held at least one master's degree, which is 20% higher than in the overall sample, and 15% held a PhD, which is nearly double the overall sample.
- The most common bachelor's degrees majors among CSEs include electrical engineering and mechanical engineering, covering more than two-thirds of the CSE dataset. This is a higher rate than seen in the general US population at the time; however, EE and ME were the two most common engineering majors when most of the CSEs were going through undergraduate education. It is also in line with the distribution of undergraduate majors across the Helix dataset.
- In contrast, at the master's level, Masters of Business Administration (MBA) is the most popular major, with almost 50% of CSEs holding an MBA. This is nearly double the rate of MBA attainment in the overall sample. Systems engineering is the second most-common master's degree field among CSEs, whereas this is the most common master's degree field in the overall Helix dataset.
- All of the CSEs in the sample have experiences across at least four of the lifecycle phases. Almost all CSEs have experienced System Definition, System Realization, and Systems Engineering Management. The most common point of entry for CSEs was System Definition.

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## **9. APPENDIX A: LIST OF HELIX PUBLICATIONS**

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### **Journal Articles**

Hutchison, N., A. Pyster, D. Henry. "Atlas: Understanding What Makes Systems Engineers Effective in the US Defense Community." *Systems Engineering*. *In process* - expected to be published in January 2017.

### **Capstone Project**

Partacz, M. 2017. "Building a Better Business Case for Systems Engineering: The Relationship between a Systems Engineer's Career Path, Proficiency and Project Performance." Capstone Project Report. Hoboken, NJ: Stevens Institute of Technology, Hoboken, NJ.

### **Conference Papers and Presentations**

Clifford, M. and N. Hutchison. 2017. "Helix: Understanding Systems Engineering Effectiveness through Modeling." Proceedings of the National Defense Industrial Association (NDIA) Systems Engineering Conference, 25 October 2017, Washington, DC.

Henry, D., N. Hutchison, A. Pyster, P. Dominick, C. Lipizzi, M. Kamil, S. Manchanda. 2014. "Summary of Findings from the Helix Project (2013-14) - An Investigation of the DNA of the Systems Engineering Workforce". Proceedings of the National Defense Industrial Association (NDIA) Systems Engineering Conference, Springfield, VA, USA, October 23-26, 2014.

Hutchison, N., D. Henry, A. Pyster, and P. Dominick. 2014. "Systems Engineering Career Analysis: Supporting a Theory of Systems Engineers." Proceedings of the INCOSE Europe, Middle-East, Africa Systems Engineering Conference (EMEASEC), Cape Town, South Africa, October 27-30, 2014.

Hutchison, N., D. Henry, A. Pyster, P. Dominick. 2014(b). "Systems Engineering Career Analysis: Supporting a Theory of Systems Engineers." Proceedings of the Europe, Middle East, and Asia Sector Systems Engineering Conference, 27-30 October 2014, Cape Town, South Africa.

Hutchison, N., Henry, D., Pyster, A., Pineda, R. 2014. "Early Findings from Interviewing Systems Engineers who Support the US Department of Defense", 2014 International Council on Systems Engineering International Symposium, June 30-July 3, 2014, Las Vegas, NV.

Hutchison, N., J. Wade, and S. Luna. 2017, "The Roles of Systems Engineers Revisited." Proceedings of the International Council on Systems Engineering (INCOSE) 27th International Symposium, 15-20 July 2017, Adelaide, Australia.

Jauregui, C., A. Pyster, D. Henry, N. Hutchison, and C. Wright. 2016. "Insights on the Experiences and Education of INCOSE-Certified Expert Systems Engineering Professionals and Chief Systems Engineers." To be published in the Proceedings of the International Council on Systems Engineering (INCOSE) 26th International Symposium, 18-21 July 2016, Edinburgh, Scotland.

Lipizzi, C., S. Manchanda, M. Kamil, A. Pyster, D. Henry, N. Hutchison. 2015. "The Education Background of INCOSE Systems Engineering Professional Certification Program Applicants." Proceedings of the International Council on Systems Engineering (INCOSE) International Symposium, Seattle, WA, July 2015.



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- Pyster, A., R. Pineda, D. Henry, N. Hutchison. 2013. "Helix: Investigating the DNA of the Systems Engineering Workforce." Proceedings of the National Defense Industrial Association (NDIA) Systems Engineering Conference, October 28-31, 2013, Crystal City, VA.
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### **Dissertation**

Hutchison, N. *A Framework to Classify Experiences and Enable Career Path Analysis to Support Maturation of Effective Systems Engineers in the Defense Industry*. PhD Dissertation. Hoboken, NJ: Stevens Institute of Technology. October 2015.

### **Journal Article**

Hutchison, N., A. Pyster, D. Henry. 2016. "Atlas: Understanding What Makes Systems Engineers Effective in the US Defense Community." *Systems Engineering*. 19(6): 510-521.

### **Workshop Reports**

Hutchison, N., D. Verma, R. Giffin, M. Clifford, A. Pyster. 2016. *Report on the Helix Early Adopter's Workshop*. Helix Early Adopter's Workshop, 20 September 2016, Ronald Reagan International Trade Center, Washington, DC.

Hutchison, N., D. Verma, P. Burke, M. Clifford, S. Luna, M. Partacz, R. Giffin. *Report on the 4<sup>th</sup> Annual Helix Workshop*. 4<sup>th</sup> Annual Helix Workshop, 17 October 2017, MITRE Campus, McLean, Virginia.

Pyster, A., D. Henry, N. Hutchison, C. Jauregui, J. Armstrong, M. Clifford. 2015. *Report on the Second Helix Workshop: Exploring the Theory of Systems Engineers' Effectiveness*. Hoboken, NJ: Systems Engineering Research Center, Stevens Institute of Technology.

Pyster, A., P. Dominick, D. Henry, N. Hutchison, C. Lipizzi, M. Kamil. 2014(a). *Report on the First Helix Workshop: Exploring the Theory of Systems Engineers' Effectiveness*. Hoboken, NJ: Systems Engineering Research Center, Stevens Institute of Technology.

### **In process**

A paper on systems engineering career paths, "Discovering Career Patterns in Systems Engineering" has been submitted for the 2018 INCOSE International Symposium. The authors are Nicole Hutchison, Sergio Luna, and Matthew Partacz.

### **Other**

ABET Symposium 2016, Fort Lauderdale, FL – ABET panel on systems engineering education and research for the 2016 ABET conference. Nicole Hutchison presented on Helix.

INCOSE Healthcare Systems Engineering Working Group Webinar – November 29, 2016. Nicole Hutchison delivered a webinar, a 60-minute overview of Atlas with specific implications related to healthcare systems engineers.

## **10. APPENDIX C: PAPER-BASED SELF-ASSESSMENT TOOLS FOR CAREER PATH**

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An individual's career path is the precise combination of experiences, mentoring, education, and training that an individual goes, particularly their characteristics, timing, and order. In order to complete a career assessment, an individual should work through the steps outlined here while filling out the career path template.

### **Experiences**

The Helix team chose to use a **position** as the unit of measure for experiences; a position is established by the organization and defines the roles and responsibilities to be performed.

Based on both the literature and the Helix data itself, each position has several characteristics:

- **Relevance:** A ‘relevant’ position is one that enables a systems engineer to develop the proficiencies critical to systems engineering. Determine a starting point for relevant experiences; this will become the first position (P1) of the career path. Fill in the title and the year(s) for the position(s).
- **Organizations:** Fill out the name of the organization for each position. This will help to show any transition or variation between organizations.
- **Roles:** A role is a collection of related systems engineering activities. Roles were identified based on the activities consistently performed by systems engineers. There are 16 roles identified in *Atlas*, as described in Table 1, below. For each position, review your activities and responsibilities and write down *all* roles played during that position.
- **Lifecycle Phases:** Generic systems engineering lifecycle phases considered in *Atlas* are based on the lifecycle phases in the *Guide to the Systems Engineering Body of Knowledge (SEBoK)*, as explained on page 5. (BKCASE Authors 2016) For each position, fill in the area(s) of the lifecycle you worked on.
- **Key Milestones.** Note any key changes in types of positions under key milestones. For example, first systems engineering role, first chief systems engineer role, first supervisory position, etc. would all be indicators of change or growth over career.

### Education and Training

Note any educational milestones or key training milestones with the position/timeline in which they occurred. Education milestones may include the completion of a degree or participation in a course that was particularly relevant or impactful for your career. Key training is training that was particularly impactful or useful for your career. You do not need to include training that did not have an impact.

### Other

Your organization may ask you to add other information, such as participation in professional societies, publications, etc. to your career path.

| Role Name                                    | Role Description |
|--|------------------|
| Roles Focused on the Systems Being Developed |                  |

| Role Name          | Role Description   |
|--------------------|--|
| Concept Creator    | Individual who holistically explores the problem or opportunity space and develops the overarching vision for a system(s) that can address this space. A major gap pointed out to the Helix team – particularly when working to implement the findings of Helix – has been that of the development of an overarching system vision. This is a critical first step in the systems lifecycle, and several organizations stated that they believed it needed to be separately called out. In addition, when looking to the future of what systems engineers need to do (e.g., INCOSE Vision 2025 (2015)), the focus on early engagement and setting the vision was deemed critical. |
| Requirements Owner | Individual who is responsible for translating customer requirements to system or sub-system requirements. This is updated from Atlas 1.0. Sheard (1996) also included the activities around functional architecture in this role. However, in working with the community, this has caused some confusion as to the differences between this role and that of “System Architect”. The Helix team believes that grouping all architecture activities together will improve clarity on the roles.   |
| System Architect   | Individual who owns or is responsible for the architectures of the system; this including functional and physical architectures. This is updated from <i>Atlas</i> 1.0. This is an update of Sheard’s “System Designer” role (1996). There was concern both at community events and during later interviews that nowhere in the presented framework did the critical role of systems engineers in architecture come out clearly. Some also argued that “Design” gave the impression that this role focuses specifically on the details of systems design over architecture.  |
| System Integrator  | Individual who provides a holistic perspective of the system; this may be the ‘technical conscience’ or ‘seeker of issues that fall in the cracks’ – particularly, someone who is concerned with interfaces. Likewise, there was concern over the word “Glue”, which many expressed was not clearly descriptive enough.  |
| System Analyst     | Individual who provides modeling or analysis support to system development activities, and helps to ensure that the system as designed meets he specification. This is unchanged from Sheard’s roles (1996).   |
| Detailed 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 an addition based on the Helix data. While systems engineers do not always get involved with detailed design, in smaller organizations or on smaller projects it is more common. Likewise, systems engineers who had played this role explained that it was critical in developing their own technical and domain expertise as well as in understanding the design approaches of   |

| Role Name  | Role Description   |
|--|--|
|  | classic engineers.   |
| V&V Engineer   | Individual who plans, conducts, or oversees verification and validation activities such as testing, demonstration, and simulation. This is unchanged from Sheard's roles (1996).   |
| Support Engineer                                     | Individual who performs the 'back end' of the systems lifecycle, who may operate the system, provide support during operation, provide guidance on maintenance, or help with disposal. This was previously titled "Logistics and Operations Engineer" in Sheard (1996). However, in interviews and at community events, the Helix team received feedback that using this title gave the impression that this role was limited and did not encompass the full spectrum of systems engineers' activities at system deployment or post-deployment. Likewise, in several organizations, "logistics" and "operations" were seen as separate disciplines from systems engineering, which caused some contention in discussions. The renaming of this category is intended to address these issues. |
| <b>Roles Focused on Process and Organization</b>     |  |
| Systems Engineering Champion                         | Individual who promotes the value of systems engineering to individuals outside of the SE community – to project managers, other engineers, or management. This may happen at the strategic level or could involve looking for areas where systems activities can provide a direct or immediate benefit on existing projects. Sheard recommended that a role such as this, labeled in her work as "Systems Engineering Evangelist", be added in (2000).  |
| Process Engineer                                     | Individual who defines and maintains the systems engineering processes as a whole and who also likely has direct ties into the business. This individual provides critical guidance on how systems engineering should be conducted within an organization context. This is unchanged from Sheard's roles (1996).   |
| <b>Roles Focused on the Teams That Build Systems</b> |  |
| Customer Interface                                   | Individual who coordinates with the customer, particularly for ensuring that the customer understands critical technical detail and that a customer's desires are, in turn, communicated to the technical team. This is unchanged from Sheard's roles (1996).  |
| Technical Manager                                    | Individual who controls cost, schedule, and resources for the <i>technical</i> aspects of a system; often someone who works in coordination with an overall project or program manager. This is unchanged from Sheard's roles  |

| Role Name           | Role Description   |
|---------------------|--|
|                     | (1996).  |
| Information Manager | Individual who is responsible for the flow of information during system development activities. This includes the systems management activities of configuration management, data management, or metrics. This is unchanged from Sheard's roles (1996).  |
| Coordinator         | Individual who brings together and brings to agreement a broad set of individuals or groups who help to resolve systems related issues. This is a critical aspect of the management of teams. This is unchanged from Sheard's roles (1996).  |
| Instructor/Teacher  | Individual who provides or oversees critical instruction on the systems engineering discipline, practices, processes, etc. This can include the development or delivery of training curriculum as well as academic instruction of formal university courses related to systems engineering. While any discipline could conceivably have an instructor role, this denotes a focus on systems and is a critical component in the development of an effective systems engineering workforce. This is an addition to the Sheard roles (1996 and 2000). |

### Systems Engineering Lifecycle

- **Concept Definition** - A set of core technical activities of SE in which the problem space and the needs of the stakeholders are closely examined. This consists of analysis of the problem space, business or mission analysis, and the definition of stakeholder needs for required services within it.
- **System Definition** - A set of core technical activities of SE, including the activities that are completed primarily in the front-end portion of the system design. This consists of the definition of system requirements, the design of one or more logical and physical architectures, and analysis and selection between possible solution options.
- **System Realization** - The activities required to build a system, integrate disparate system elements, and ensure that a system both meets the needs of stakeholders and aligns with the requirements identified in the system definition stage. This includes integration, verification, and validation (IV&V).
- **System Deployment and Use** - A set of core technical activities of SE to ensure that the developed system is operationally acceptable and that the responsibility for the effective, efficient, and safe operations of the system is transferred to the owner. Considerations for deployment and use must be included throughout the system life

cycle. Activities within this stage include deployment, operation, maintenance, and logistics.

- **Product and Service Life Management** - Deals with the overall life cycle planning and support of a system. The life of a product or service spans a considerably longer period of time than the time required to design and develop the system. This stage includes service life extension, updates, upgrades, and modernization, and disposal and retirement. The organizations in the current sample are primarily concentrated on new development, so this is a very under-represented aspect of the life cycle.
- In addition to these life cycle phases, the SEBoK includes orthogonal activities of systems engineers, **Systems Engineering Management**, defined as managing the resources and assets allocated to perform SE activities. Activities include planning, assessment and control, risk management, measurement, decision management, configuration management, information management, and quality management. These activities can occur at any point in the systems engineering lifecycle.

### Career Path Self-Assessment Tool

Date: \_\_\_\_\_

|   |   |  |  |  |  |  |  |  |  |  |
|---|---|--|--|--|--|--|--|--|--|--|
| Concept Definition  |   |  |  |  |  |  |  |  |  |  |
| System Definition   |   |  |  |  |  |  |  |  |  |  |
| System Realization  |   |  |  |  |  |  |  |  |  |  |
| System Deployment and Use                                   |   |  |  |  |  |  |  |  |  |  |
| Product and Service Life Management                         |   |  |  |  |  |  |  |  |  |  |
| Systems Engineering Management                              |   |  |  |  |  |  |  |  |  |  |
| Role(s)<br>Performed  | } |  |  |  |  |  |  |  |  |  |
|   |   |  |  |  |  |  |  |  |  |  |
| Domain(s)   | } |  |  |  |  |  |  |  |  |  |
|   |   |  |  |  |  |  |  |  |  |  |
| System<br>Characteristics                                   | } |  |  |  |  |  |  |  |  |  |
|   |   |  |  |  |  |  |  |  |  |  |
| Position  | } |  |  |  |  |  |  |  |  |  |
| Organization(s)   | } |  |  |  |  |  |  |  |  |  |
| Dates   | } |  |  |  |  |  |  |  |  |  |
| Milestones<br>(Key positions,<br>education, or<br>training) | } |  |  |  |  |  |  |  |  |  |
|   |   |  |  |  |  |  |  |  |  |  |