Helix – Phase 3

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The Helix project is heavily reliant upon data primarily collected through interviews. The team would like to thank each organization that has participated, the points-of-contact who made it possible for the team to visit the organizations, and every interviewee who gave up hours of time to the project. When allowed, interviews are recorded and transcribed. We would like to thank our transcriber, Mary Ratliff, for her assistance in our efforts.

Finally, Dr. Ricardo Pineda, the Co-Principal Investigator on Helix, passed away unexpectedly just before this report was published. We are all deeply saddened by his passing but much better for the time we had with him and the many insights and inspiration he offered. He was a wonderful friend who will be missed.

EXECUTIVE SUMMARY

Helix, a project of the Systems Engineering Research Center (SERC), is a multi-year longitudinal study designed to build an understanding of the landscape of the systems engineering workforce, what enables and inhibits the effectiveness of systems engineers, and how organizations are attempting to improve their effectiveness.

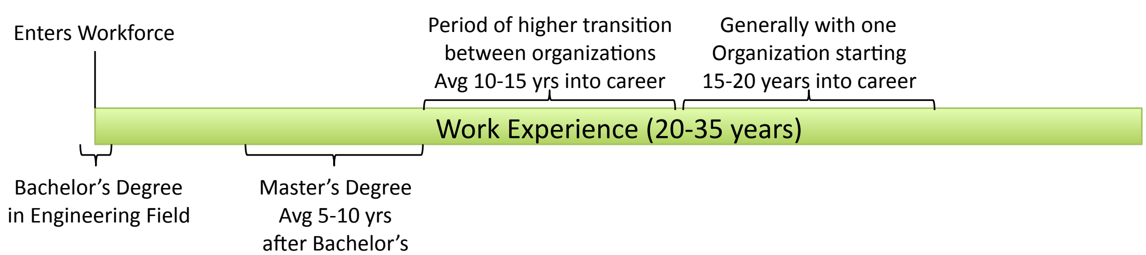
Helix is exploring three research questions:

- What are the characteristics of systems engineers?
- How effective are systems engineers and why?
- What are employers doing to improve the effectiveness of their systems engineers?

The first Helix Report (Pyster et al. 2013) was published in December 2013, which provided an overview of the motivation and methodology for the study as well as some preliminary results for Phases 1 and 2 of the project; one of the findings on 'What makes Systems Engineers most Effective' was the importance of diversity of experiences and mentoring. This report presents findings in Phase 3 and explores these two themes in more detail. The analysis is based on the data collected during Phases 1 and 2 plus follow up interviews conducted during Phase 3.

The career path analysis looks at several aspects of work experiences relevant to the development of systems engineers. This includes experiences across the system life cycle as well as different types of organizations, domains, programs, and roles. This analysis also includes the development and application of seniority levels – junior, mid---level, and senior – for systems engineers. Finally, the Helix team analyzed the careers of chief systems engineers to determine a common path, summarized below.

Typical Career Path for Chief Systems Engineers



Additional analysis includes a definition of mentoring and a classification for mentoring approaches, the benefits of mentoring, why mentoring is important for systems engineers, requirements for successful mentoring, and recommendations on mentoring for organizations.

The Helix team will use the results of the first two reports, additional data collected, and future analysis to build a theory of systems engineers that offers explanatory and predictive power to guide career decisions by individuals, and to shape policies and initiatives by organizations with respect to their systems engineering workforce. The first thoughts on this theory – including the importance of personal experiences and characteristics, and the environment – are outlined in this report. Broadly, effectiveness in a systems engineering role would be defined or predicted based on these variables:

Effectiveness in a role = *f* (experiences, characteristics, environment)

The team will use this starting point to build a role-based theory of systems engineers that can be used by individuals and organizations to enable career planning.

1. INTRODUCTION

The US Department of Defense (DoD) and the Defense Industrial Base (DIB), comprising contractors that develop and deliver systems to the DoD, have been facing major systems engineering challenges in recent years (e.g. GAO 2008, 2011, 2012). Mission requirements are evolving and they demand ever more sophisticated and complex systems (e.g. Boehm et al. 2010; INCOSE Technical Operations 2007; Davidz and Nightingale 2007, Frank et al. 2007); the tools, processes, and technologies that systems engineers must master keep changing more rapidly (e.g. Frank 2006); and budgets and schedules are being compressed dramatically. Certainly, one of the more significant concerns is that thousands of systems engineers in the defense workforce are nearing retirement and will be taking with them hundreds of thousands of staff-years of experience as presented in "SPRDE Functional Career Field: Critical Acquisition Workforce Data FY 2013-Q3."(DoD 2013)

Organizations have responded to these challenges in a variety of ways, such as offering extended training and education to their current workforce or systematically seeking to select specialty engineers with promise as systems engineers and incorporating them into the ranks of systems engineers. Unknown is whether these actions are producing the desired results because there is no common understanding of the diverse roles that systems engineers play; how they are selected and evaluated; what competencies are most important for different roles; how to evaluate effectiveness; or how experience impacts effectiveness. These and many other insights will be critical to maintaining and growing the systems engineering workforce in the US DoD and DIB.

In order to provide these insights, the Systems Engineering Research Center (SERC), a US DoD University Affiliated Research Center (UARC), has initiated the Helix Project to investigate the "DNA" of the defense systems engineering workforce. The US Deputy Assistant Secretary of Defense for Systems Engineering (DASD(SE)) 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, the DoD and NDIA-SED have formed the Helix Advisory Panel (HAP) with representatives primarily from both organizations.

Helix is a multi-year longitudinal research project, which is gathering data from many DoD and DIB organizations through a combination of techniques, including interviews with hundreds of systems engineers. In late 2014, Helix expects to reach beyond DoD and the DIB to gather data from other types of organizations as well. This may include non-defense organizations in the US or non-US organizations.

This technical report is the second published by Helix and presents findings beyond those of the first report, which was published in December 2013. (Pyster et al. 2013) It is a snapshot of the research project at this moment. As such, some of the research results are rather preliminary, while others are more mature. The findings presented here are based on the interviews conducted with over 100 systems engineers from seven organizations in 2013, their resumes, and follow up interviews with 21 of these systems engineers. This report is organized as follows:

- Section 2 explains updates in the research methodology
- Section 3 offers first thoughts on an emerging theory of systems engineers
- Section 4 provides the current level of analysis on career paths for systems engineers
- Section 5 provides more in-depth discussion on the role of mentoring in systems engineers' development
- Section 6 provides an overview of the future directions for Helix.

2. PHASE 3 RESEARCH METHODOLOGY

Although there have been small refinements, the Helix methodology has not changed significantly since the publication of the first Helix report in December 2013, as shown in Figure 1. In Phases 1 and 2 of the project, the team focused primarily on initial interviews and analysis with subsequent reporting (Steps A, B1-B3, C1-C3, D, and E). In Phase 3, the Helix team has focused data collection effort primarily around follow up interviews (B4), has conducted additional analysis (C4 and C5), and has reviewed the methodology (F), as highlighted in red in Figure 1. The team has also focused on the end stage goals for addressing the research questions (D). The methods used for each of these focus areas are outlined below.

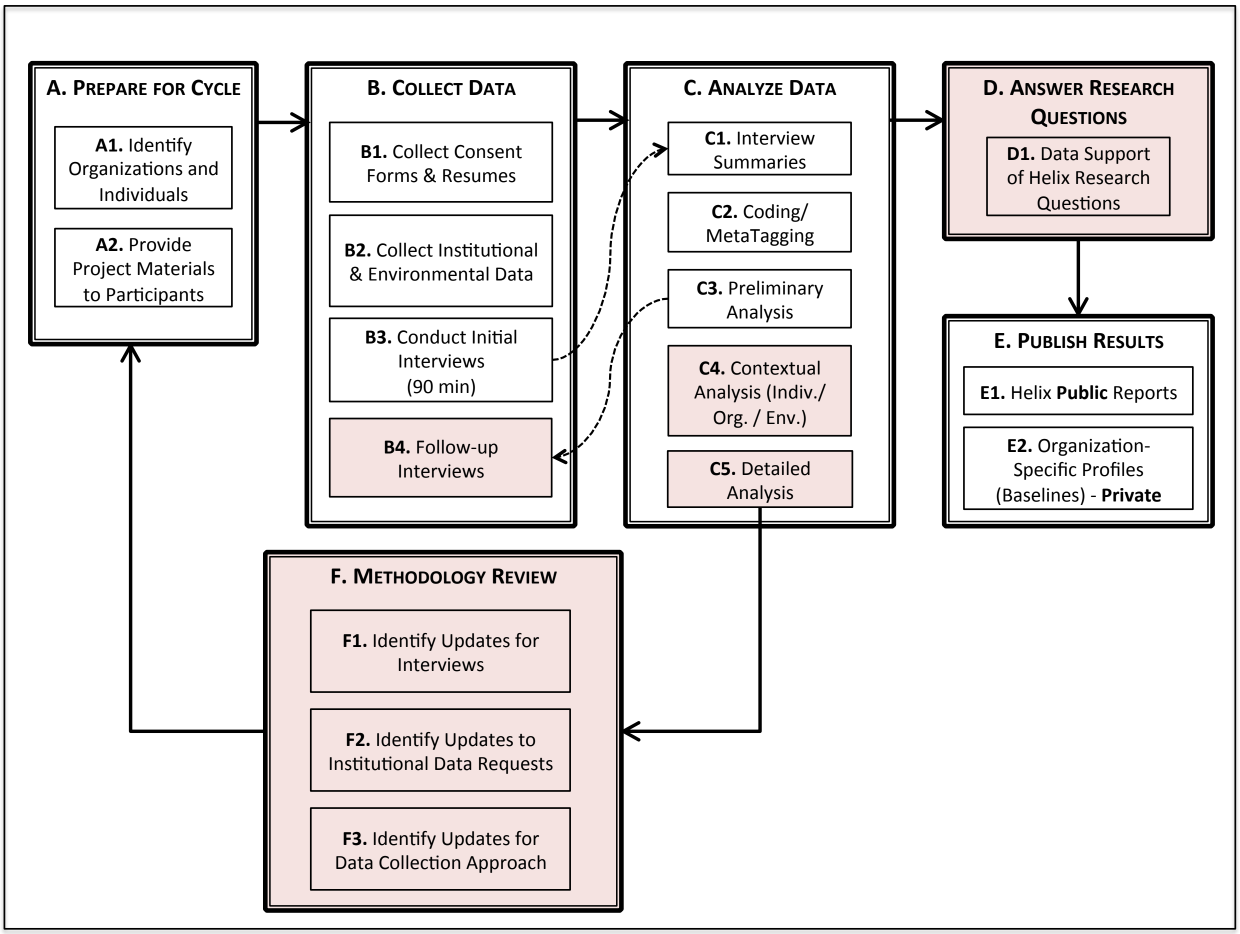


Figure 1. Helix research methodology overview.

2.1 FOLLOW UP INTERVIEWS (B4)

Follow up interviews represent the majority of the new data added to Helix In Phase 3. The team piloted the follow up interview process, refined the questions, and has been working on full-scale follow up interviews. The follow up interview process is parallel to the initial interview process, with a few differences. At a high level, the interviews are shorter (limited to 60 minutes), are conducted over the phone instead of in person, and are all conducted individually (whereas many of the initial interviews are conducted in small groups). The steps for conducting follow up interviews include:

1. The Helix team creates a career profile (see Section 4 below). This is used to identify any questions about the interviewee's background, experiences, education, etc. that may not have been addressed in the first interview.

2. The team reviews the transcript or summary from the individual's first interview and identifies any points of confusion, concern, or areas of interest that need to be addressed in the follow up interview.

3. The team asks questions of the individual over the phone. A standard set of follow up questions have been developed – tailored to the seniority of the systems engineer – that are asked during follow up interviews. These questions can be found in Appendix A.

As with the initial interviews, data collection is done in one of two ways: when recording is allowed, a transcript is created and data analysis is done using this transcript; when recording is not allowed, the team takes detailed notes during these interviews, cleans up the notes, and uses these for data analysis.

2.2 Additional Analysis (C4 and C5)

The Helix team has added a new aspect to its analysis of data collected in Phases 1 and 2. This is the use of demographic, background, and interview data to develop career profiles for the individuals who have participated in the study. The team has used this mix of information to develop a profile that explains how each individual's career has changed over time. When possible, the team used interview data (from either initial or follow up interviews) to determine the reasons for some of these changes.

There are several aspects being examined in the career path analysis, including current seniority levels of interviewees and multiple aspects of each individual's experiences such as the stages of the life cycles, types of programs, types of systems, areas of responsibility, and roles played.

Additional detail on the career path analysis to date is found in Section 4.

2.3 Methodology Review (F)

The team has reviewed its records of the methods used during interviews and for analysis to date. The team believes that these are still sound, but has made a few minor updates to the specific questions or tools used for data collection in order to achieve more consistent or meaningful results. Specifically, the team revised the questions for the initial interviews by:

- Reviewing the way questions were asked in interviews over time and, in the event of multiple methods for asking a question (i.e. different phrasing), determining which of the options provided the best or most reliable answers;

- Identifying questions which have not traditionally provided clear or useful answers and either modifying these or substituting additional questions, which were piloted in the follow up interviews; and

- Identifying new questions from the follow up interviews that should become part of the initial interview.

The updates to the interview questions can be found in Appendix B. These updates were submitted to and approved by the Stevens Institute of Technology Institutional Review Board (IRB). They will be implemented in new interviews during Phase 4.

2.4 Move from Grounded Theory to a More Intentional Research Focus

The Helix team began with a modified grounded theory approach. Grounded theory requires entering the research without any pre-conceptions about possible results. The team reviewed all data with an unbiased perspective, focusing on looking for patterns and anomalies to guide further analysis. After nine months of data collection and review, the team has identified patterns in the data and particular areas of interest for the project. Some of these patterns include:

- The different paths taken by individuals in order to become and mature as systems engineers;
- The role of experiences in systems engineering careers;
- The role of mentoring in the maturation of systems engineers;
- The differences and similarities between systems engineering in government and industry;
- The use of process to supplement experience and the balance between process and critical thinking; and
- The definition of effectiveness for systems engineers, including critical behaviors, and how that can be assessed outside of standard human resource style processes.

Going forward, the team will begin focusing on these areas of interest. Early examples of this are the analyses of career paths and mentoring, found in Sections 4 and 5, respectively, as well as in the updated questions shown in Appendices A and B. The Helix team will continue to investigate these areas, and anticipates that these elements will be crucial components in developing a theory of systems engineers.

2.5 Answer Research Questions (D)

In its first report, the Helix team linked the preliminary findings to the research questions, and this work continued in Phase 3. The team is now able to offer a preliminary view on a theory that would help to explain systems engineers as a whole, and would provide actionable information and data-based guidance for workforce development in systems engineering. This effort to establish a theory of systems engineers reflects the team's deeper understanding of the data towards addressing the research questions.

Additional detail about how a theory of systems engineers may be built – and the current data and analysis that support this – are discussed in Section 3.

3. Towards a Theory of Systems Engineers

The primary purpose of Helix is to provide a data-driven understanding of the current systems engineering workforce – what motivates them and why; what enables and jeopardizes their effectiveness and why; what steps individuals and organizations could take to improve that workforce; and why those steps would help. A goal of the Helix project, then, is to develop a theory of systems engineers that offers explanatory and predictive power to guide career decisions by individuals and shape policies and initiatives by organizations with respect to their systems engineering workforce.

Developing such a theory is clearly challenging and is something that will evolve incrementally over several years. Based on the data collected to date and the subsequent analysis of that data, the Helix team has developed an early framing of a theory which is expected to evolve significantly over the next couple of years.

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

1. Personal **experiences** (what he has done, including where he has worked and on what types of systems he has worked)
2. Personal **characteristics**, including both technical and general capabilities (who he is and what he knows),
3. **Environment** in which a systems engineer operates (where he works and what types of systems the organization works on)

Note that the *personal experiences* variable is about systems engineer's past, while the other two variables are about the systems engineer's present.

Applications of such a theory could include guiding an individual systems engineer to

- Seek specific new experiences to improve his effectiveness;
- Hone specific personal capabilities to improve his effectiveness (such as by targeted training and education), mindful of his personal characteristics;
- Understand the impact of the environment in which he operates and to consider what changes in his environment – such as by changing where he works – to seek, if any; and to
- Reflect on strengths and limitations in how effective he is likely to become, based on personal qualities that enable and limit the range of experiences he is likely to seek, and competencies he is likely to gain, the roles he is likely to play, and the environment in which he is likely to be able to work.

Moreover, such a theory could help guide an organization to shape its policies, to foster a culture, to define systems engineering roles, and to create workforce development initiatives. This would enhance the collective experiences, traits, and capabilities of its systems engineering workforce; improve the environment in which its systems engineers work; and address the limitations and risks to the organization in their efforts.

Simplistically, this theory could be represented as the following function, although the team anticipates that the actual relationship will be far more complex and be variable over time, than what is implied by this simple formula:

Effectiveness in a role = *f* (experiences, characteristics, environment)

Based on the findings in the first Helix technical report and the analysis performed for this report, anticipated relationships between those three variables and effectiveness include:

- Experience generally correlates positively with greater effectiveness. Having more diverse experiences, which expose an individual to multiple domains, life cycle models, and life cycle phases appears to accelerate the speed with which one becomes effective and the degree to which one can be effective.
- Certain characteristics and capabilities correlate positively with greater effectiveness. Systems engineers often hold seemingly contradictory characteristics; e.g., a good systems engineer is capable of both big picture thinking *and* attention to detail, is both strategic *and* tactical, and is both courageous *and* humble. (Pyster, et al. 2013, Section 6.2.1.1.1) Systems engineers are technically competent in the domain in which they work, often with deeper technical competence in one or more aspects of that domain. (Pyster, et al. 2013, Section 6.2.1.2) Such characteristics and capabilities seem common across most systems engineer roles.
- Certain environments correlate negatively with effectiveness; e.g., an organization where there is an ambiguous definition of the term "systems engineering" (Pyster, et al. 2013, Section 6.2.4.1) or where there the title "systems engineer" is used unclearly (Pyster, et al. 2013, Section 6.2.4.2), inhibit the effectiveness of systems engineers.

Section 4 of this report examines the various roles that systems engineers typically play and the types of experiences they typically have throughout their careers. This research, while still early, is foundational to developing the theory since effectiveness must be understood in the context of specific roles.

Section 5 examines the way in which mentoring impacts effectiveness and the variety of ways in which organizations approach mentoring. Strong mentoring can:

- Inform an individual about the experiences he should seek to advance his career and help him secure an opportunity to gain those experiences.
- Guide an individual into reflecting on the strengths and weaknesses of his personal characteristics and capabilities and how to leverage his strengths and address his weaknesses to perform the current roles he plays and prepare for future roles he seeks.
- Help an individual understand and navigate the environment, mitigating the negative aspects of the environment in which the systems engineer works and accelerating how quickly a systems engineer learns to navigate the environment successfully, avoiding pitfalls and build a personal relationship network.

The Helix team will strive to develop a richer insight into the theory of systems engineers in subsequent technical reports.

4. TOWARDS THE THEORY: CAREER PATH ANALYSIS

Workforce planning and improvement activities must start by identifying the subject "workforce". As discussed in the first Helix report published in December 2013, there is no consistent definition of "systems engineer" across the community; the term is used inconsistently in titles across organizations, and in some cases even within a single organization. (Pyster et al. 2013) Some organizations that perform systems engineering activities do not use the title of systems engineer at all. The analysis presented in this section seeks to answer the question of "who" systems engineers are by examining the variety of experiences that systems engineers have had, looking at career paths of junior, mid-level, and senior systems engineers. At this time, most of the data analyzed (about 60%) for this section of the report was from DIB employees, not DoD employees; hence, most insights reflect a skewed sample. The next Helix report, expected in autumn 2014, will include data from a larger number of DoD employees.

4.1 CAREER PATH ANALYSIS METHODOLOGY

This initial analysis includes the information for 42 of the 110 systems engineers from the participating organizations. The general approach for this analysis included:

- Review of resumes submitted by each individual;
- Review of first interview transcripts and notes; and
- Review of preliminary results during follow up interviews to clarify analysis. Roughly half of the individuals in the career analysis sample have participated in follow up interviews.

Career path analysis examines several aspects of an individual's career, including:

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

These aspects are reported in aggregate below and, where possible, with differences in gender or seniority. It is important to caveat these results with the fact that most of the data has come from resumes and the initial interviews, which did not consistently provide this level of detail for all interviewees. For example, some individuals may have worked on more types of programs than they reported in their resumes or revealed in their initial interviews. The Helix team will continue to gather additional data and validate or revise its initial findings via follow up interviews.

Note that because there are only two mid-level systems engineers in the current sample, they may be characterized in the findings, but are not always included in the figures, particularly where this would lead the reader to emphasize the information, which is inappropriate with such a small sample size.

4.2 SENIORITY LEVELS OF SYSTEMS ENGINEERS

It is useful to distinguish Helix findings based on the seniority levels of the participants, providing insight into how the findings vary between systems engineers new to the field and to those who have been systems engineers for many years; the first Helix report did not make such a distinction. Placing people in levels is more difficult in systems engineering than in traditional engineering fields due to inconsistencies in titles, roles, and in identifying when someone becomes a systems engineer. For example, someone who comes into an organization with a bachelor's degree in electrical engineering usually has a clear identity as an electrical engineer. That person maintains his 'electrical engineer' identify for years, perhaps for his entire career, even as he takes on increasingly more complex technical challenges and projects. On the other hand, that same electrical engineer may begin performing systems engineering related tasks early in his career while still being identified as an electrical engineer. There is no consistent point, either across the community or even within a single organization, at which the individual or the organization recognizes that the systems engineering tasks have come to dominate that individual's role and that he is now a 'systems engineer' more than an 'electrical engineer'.

In some organizations, systems engineers are not formally identified, which makes distinguishing the seniority of systems engineers even more difficult. Even in organizations that formally identify systems engineering as a career field, there are exceptions to the process. For example, leaders in one organization explained that their process requires individuals to show systems capabilities in general engineering fields before becoming systems engineers – but even within that organization, the Helix team interviewed individuals who became systems engineers immediately out of college.

The Helix team determined criteria for determining the seniority of systems engineers that would allow for diversity across and within organizations. Figure 2 provides the initial criteria used to distinguish seniority levels.

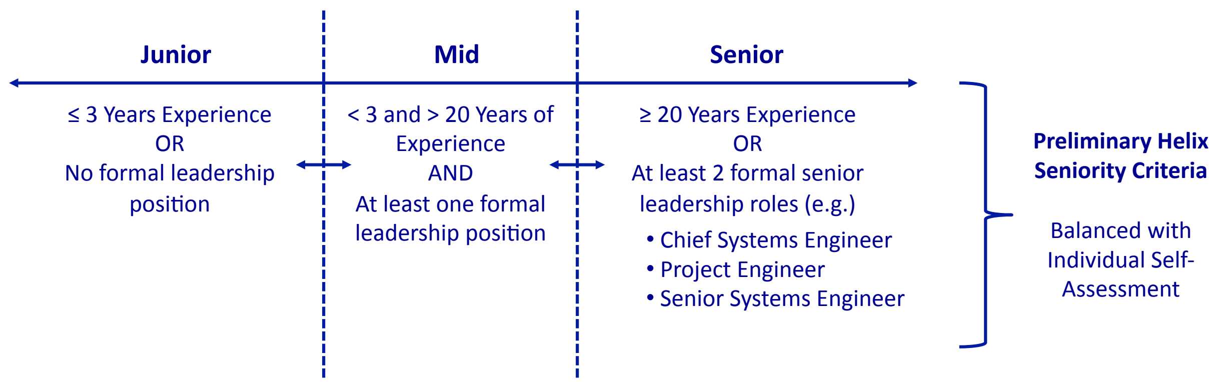


Figure 2. Preliminary criteria for identifying individuals by seniority.

The breaks between categories are heuristic, not principled, but are also largely consistent with how the interviewees tended to view themselves.

- A systems engineer with less than 3 years of experience is considered junior.
- A systems engineer who has never held a formal leadership role, regardless of years of experience, is considered junior.[1] This aligns with data from the follow up interviews, where most participants considered junior systems engineers to be individual contributors, who have not yet had any formal leadership positions as systems engineers.
- A systems engineer with over 20 years of systems engineering experience is automatically considered senior.

[1] The term "formal leadership role" is important here. Because of the nature of systems engineering, effective systems engineers at all levels must exhibit some leadership behaviors such as influencing or negotiating. The distinction here is that there must be some positional authority assigned by the organization. The Helix team will explore the differences between leadership behaviors and leadership positions going forward.

- Within each organization there are certain roles, such as "program engineer", "project engineer", "chief systems engineer", and "senior systems engineer" that are only played by the most experienced systems engineers. Therefore, an individual who has played one of these roles is considered senior.
- By definition, mid-level systems engineers are those who are neither junior nor senior, having some characteristics of both:
    - Mid-level systems engineers often act as both individual contributors and leaders of small teams. A mid-level systems engineer must have held at least one small-scale formal leadership role in their professional experiences.
    - Mid-level systems engineers have more than three years of experience and less than 20. But it is also important to understand what these systems engineers have done in order to classify them. For example, an individual who has five years of experience but has never had a leadership role would still be considered a junior systems engineer.

The Helix team will continue to refine the criteria used to categorize individuals by seniority. As an additional validation of the categories, the Helix team asked those who participated in follow up interviews to self-identify as junior, mid-level, or senior and to explain their rationale. The majority of self-identifications matched the Helix team's assessments. In some cases, however, an individual self-identified with a different seniority level. When the rationale for this decision provided new data that was not part of the initial Helix assessment and this information provided insight with respect to the above criteria, the Helix team updated the assessment. When the rationale did not provide new data about the individual but instead was related to organization-specific context, the Helix team retained the Helix assessment.

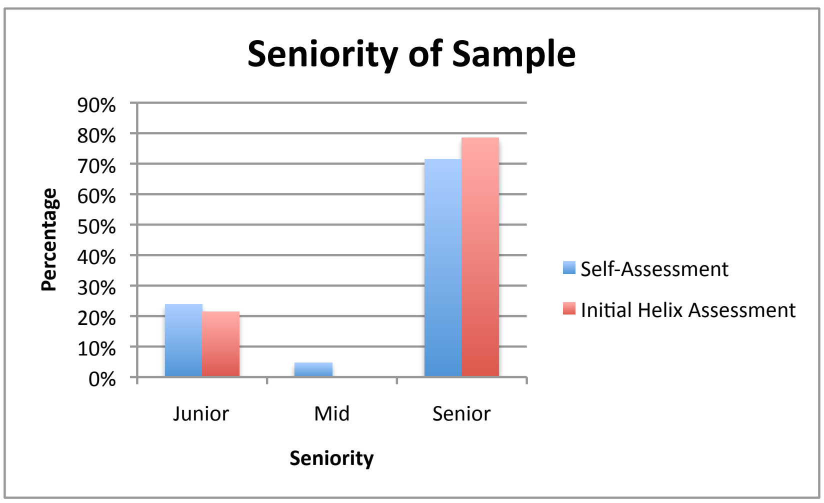


Figure 3. Overview of the sample by seniority.

Figure 3 shows that almost 80% of participants to date have been senior-level systems engineers; mid-level systems engineers are the most under-represented group in the current sample. It is unclear if this reflects the seniority of the wider population or if this is an artifact of how organizations selected interviewees. This profile does overlap the profile of the DoD systems engineering workforce by age, as seen in Welby (2010), reproduced in Figure 4 below. Welby's diagram uses age, while the Helix seniority assessment uses a number of criteria but not age, directly. It is interesting to note that the shape of the sample population and the DoD population are similar. The Helix sample is most lacking in mid-level systems engineers; while the team will specifically seek to interview more mid-level systems engineers in future interviews, the overlay of Figure 4 indicates that this could be a reflection of the population.

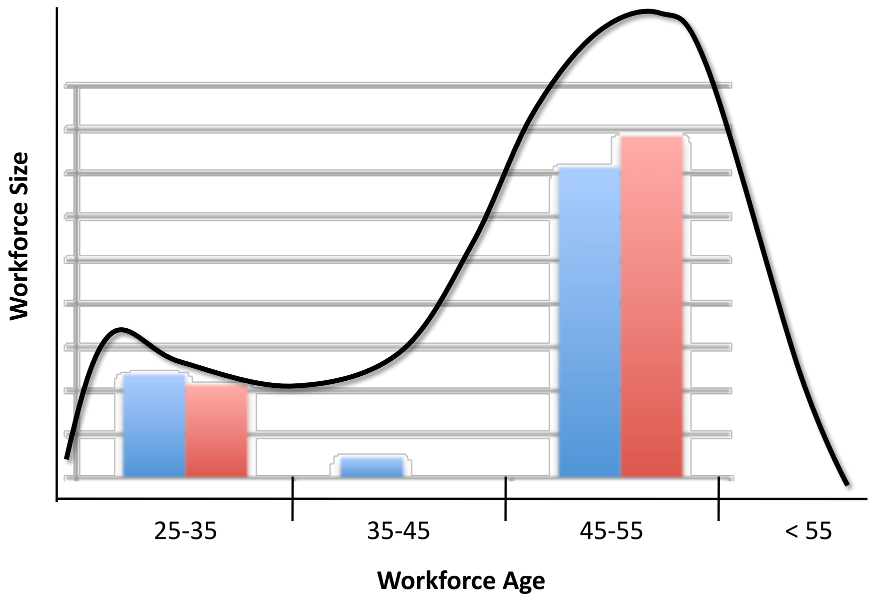


Figure 4. An overlay of the seniority of the current Helix sample (by percentage) and the overall shape of the DoD systems engineering population by age (Welby 2010).

In two instances, individuals identified as senior by the Helix team self-identified as mid-level. In both instances, these individuals felt that they were strong individual contributors who have led very small projects, but have not yet had sufficient experience in formal leadership roles at a scale to consider themselves senior. A third individual was classified as senior by the team but self-reported as junior, not because of experience or responsibilities, but because this individual was at a junior level within the organization in terms of compensation. The Helix team considers this individual to be senior, as compensation is not a factor in the current criteria. The Helix team will continue its analysis beyond the current 42 individuals and discuss results with individuals during follow up interviews.

4.3 Career Paths for Senior Systems Engineers

One of the goals of Helix is to understand how senior systems engineers have progressed through their careers. The team can then compare this historical perspective to the current career paths of lower seniority systems engineers, to help determine areas of differences in early experiences between the current generation and the future generations of senior systems engineers. Going forward, the Helix team will use interviews to explore what these differences may mean.

For this report, the team focused on detailing the careers of chief systems engineers. In future reports, the team proposes to add detail for at least program/project engineers, which is another relatively common senior systems engineering position.

4.3.1 Career Path for Chief Systems Engineers

The team has scoped this analysis to a specific role that is played by senior systems engineers: a chief systems engineer. The term "chief systems engineer" is not used in all organizations participating in Helix, but is common enough to be applied. In this context:

- A **chief systems engineer (CSE)** is responsible for the technical aspects of a program, acting across the program life cycle and providing coordination and, when necessary, negotiation across a number of engineering specialties to develop a system solution and an appropriate process to realize that solution. The CSE often has direct interaction with the customer as well as oversight of other systems engineers and/or engineering personnel within a program.

The Helix team has identified ten individuals in the current sample that are currently playing the role of CSE. Nine of these are in industry and one is in government. Because of the nature of government acquisition efforts – where government systems engineers often review work done by contractors – it is not surprising that few of the government participants to date have played the role of CSE.

Figure 5 provides an overview of the most common career path for the CSE in the sample. As the Helix team adds data to this analysis, this view of CSEs' careers will become richer and will hopefully include more examples from government.

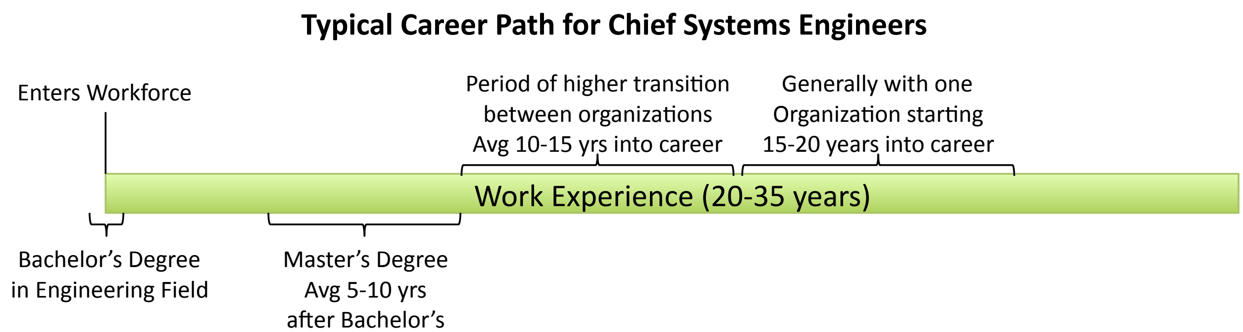


Figure 5. Overview of the common career path for chief systems engineers.

The CSEs, in the sample, have from 20-35 years of experience in the workforce. Most of them entered the workforce after graduating with a bachelor's degree; three individuals entered the workforce while completing their degrees. Most CSEs then stayed in the same organization for several years, with over half of them earning a master's degree 5-10 years into their careers. About 40% of the chief systems engineers worked in only one organization during their entire careers. The remaining 60% changed organizations primarily in the 10-15 year range, and then stabilized in their current organization between 15 and 20 years into their careers. Additional observations about careers for CSEs include:

- All of the CSEs in the current sample have experience across 4 stages of the life cycle. (Details on and definitions of the life cycles outlined in Section 4.5, below.)
    - About half gained their first experiences in System Definition, which includes traditional development activities.
    - Two had their first experiences in Concept Definition; one in Deployment and Use (a member of the military who maintained systems); and one in System Realization.
    - All but one chief systems engineer has experience in Concept Definition.
    - All chief systems engineers have experience in System Definition and System Realization.
    - Half of the chief systems engineers have experience in Systems Deployment and Use; the other half in Systems Engineering Management.

- The roles played by CSEs are outlined in Figure 6. Additional detail on the roles analysis can be found in Section 4.8, below.

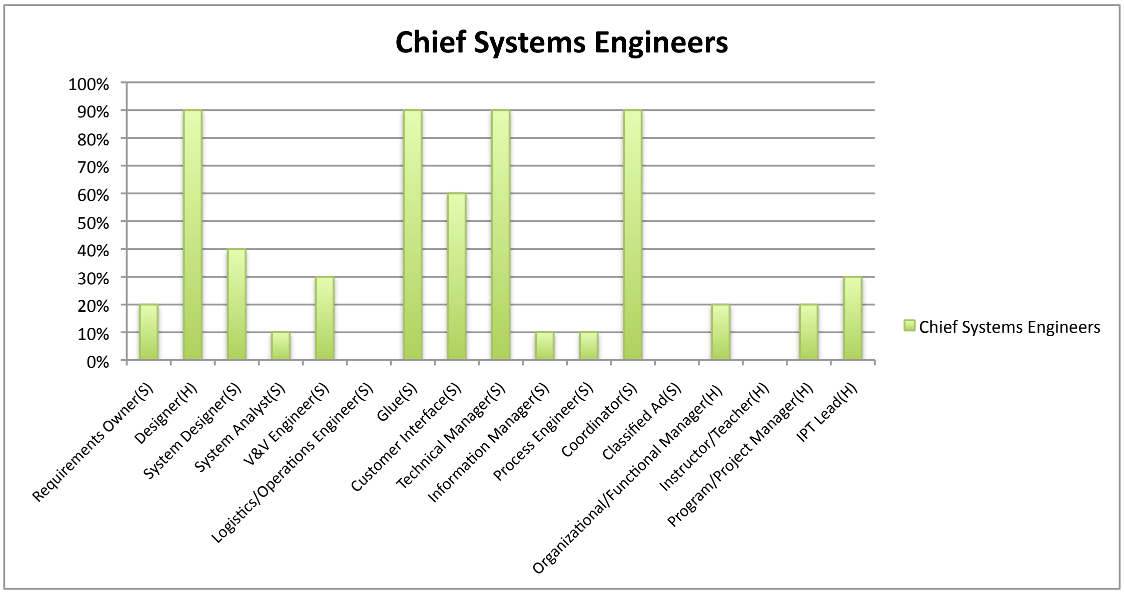


Figure 6. Roles played by chief systems engineers over their careers.

  - The only roles that have *not* been played by the CSEs in the sample are Logistics/Operations Engineer; Instructor/Teacher; and 'Classified Ad' systems engineer (generally an engineer of IT systems). These roles are also have low representation in the wider sample.
  - The role of Designer (design as a specialty engineer) has been played by 90% of the CSEs.
  - The other life-cycle related roles are less common, with only 40% playing the role of System Designer (Architect) and less than 30% playing the roles of Requirements Owners, System Analysts, or V&V Engineers. When they were performed, these roles have generally occurred earlier in the career.
  - In the non-life cycle-specific roles, 90% of CSEs have been the Glue, Technical Manager, and Coordinator; 60% have experience interfacing directly with the customer. Only 10% have performed Information Management or Process Engineering roles. These roles have all generally been performed later in the careers of chief systems engineers.
  - A few of the CSEs also have experience as managers within systems engineering organizations or as program managers and 30% have led IPT efforts, mostly earlier in their careers.
- Regarding the education of these CSEs:
  - Only one individual had an associates degree
  - All have bachelor of science degrees; 1 individual also has a bachelor of arts degree
    - Eight of these degrees are in electrical engineering; one is in mechanical engineering, and one is unspecified. Electrical engineering is a core capability for

a few of the organizations that have participated in Helix to date; therefore the focus on electrical engineering in education is not surprising and may not be representative of the wider population of chief systems engineers.

  - 60% have master of science degrees; this is the same as the average for the total sample.
    - Four of these degrees are in electrical engineering; one is in electrical, electronics, and communication; and one is in computer engineering.
  - 20% have master of business administration (MBA) degrees; this is twice the average for the total sample.
  - One individual has a PhD.

- CSEs overall had less movement between organizations during their early careers than do current junior systems engineers. The majority of junior systems engineers have experience at 2-4 organizations in their careers, whereas 80% of the CSEs stayed at the same organization for the first 3 years of their careers and around 35% had experience at one or two organizations. (See Figure 10 in section 4.4.1, below).

In Phase 4, the Helix team will complete this analysis for all chief systems engineers across the 110 interviewed systems engineers as well as any added to the sample during new interviews.

4.4 Experiences across Organizations

One aspect of a career path is the number of different organizations an individual works for over the span of his career. According to interview data, working for different organizations exposes individuals to a variety of factors including multiple cultures, missions, types of systems, application domains, business processes, and systems processes. At present, the Helix team can provide specific insights into two aspects of organizational experiences: 1) the number of different organizations at which an individual has experience, and 2) whether these organizations have been in government, industry, or a mixture of the two.

4.4.1 Experience by Number of Organizations

Though counting the number of organizations seems straightforward, there were a few challenges to this analysis:

- For industry experiences, many of the companies within the DIB have merged and split over time. The challenge was to determine whether these organizations should be considered as one or several. Based on guidance from senior systems engineers as to why working for multiple companies may be beneficial (explained below), the team asked about these transitions in the follow up interviews. T*he Helix team has determined that there are sufficient differences in organizational culture, process, and/or scope to consider these to be multiple organizations for this analysis.*
- For government organizations a similar question arose. This challenge primarily arose from individuals staying within a high-level umbrella organization, but moving to several different components of that organization. For example, an individual working within a program executive office (PEO), but moving to provide support to the individual program offices within the PEO. As with the industrial counterpart, the team reviewed interview data about the differences as these varying levels. *The Helix team determined that, in general, culture or scope*

varied greatly, and these instances are considered to be different organizations for the purposes of this analysis.

Using the assessment criteria explained above, Figure 7 shows the profile of the number of organizations in which an individual has worked by seniority.

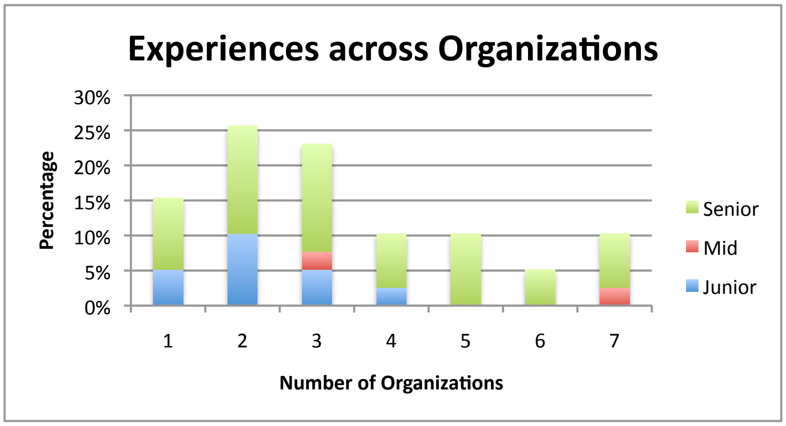


Figure 7.The number of organizations worked in by each individual in the sample.

Of the 28 senior systems engineers in the current analysis, over half have worked in three or fewer organizations during their careers; while almost 40% have worked in four or more. As there are only two mid-level systems engineers in the current sample, no trends can be identified. A third of the junior systems engineers have already had experiences at three or four organizations. Several interviewees have anecdotally noted that they believe that junior members of the workforce in general are much more likely to move to new organizations in search of different opportunities. This may account for higher diversity of organizations earlier in the careers of junior systems engineers.

Another view of the data is provided in Figure 8, below. This shows a comparison of the number of organizations for junior systems engineers (current) and the number worked in the first three years of senior systems engineers' careers (when they would have been considered "junior" by the Helix criteria).

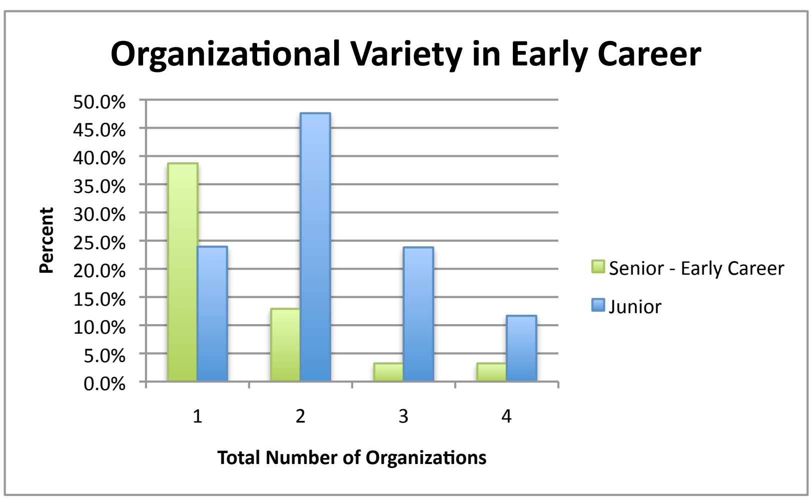


Figure 8. Comparison of the number of organizations worked in by current junior systems engineers and senior systems engineers in the first three years of their careers.

The percentages in Figure 8 are the percentage of individuals at that seniority level, not the percentage of the full sample. It is immediately evident that junior systems engineers show much more movement in their careers to date than senior systems engineers did early in their careers:

- Almost 40% of senior systems engineers stayed with a single organization in the first three years while less than 25% of junior systems engineers have remained in one organization.
- Nearly 30% more junior systems engineers have experience at three organizations than senior systems engineers did early in their careers.
- Nearly 20% more junior systems engineers have experience at three organizations than senior systems engineers did early in their careers.
- Over 10% of the junior systems engineers already have experience at four organizations; less than 5% of senior systems engineers had this level of variety early in their careers.

In follow up interviews, senior systems engineers have been asked to explain what career guidance they would recommend for younger systems engineers. There have been two recurring recommendations with regard to working for different organizations:

- Experience more than one organization in order to participate in different processes and best practices; and
- Stay with an organization long enough to learn their methods of business and their systems engineering approaches.

Though seemingly paradoxical, this advice makes sense in context. Many senior systems engineers, both in initial and follow up interviews, have stated that they have seen junior systems engineers who leave the organization before they have a chance to really understand the business. There are a few reasons cited for this in the interviews:

- **Positional Impatience** – several senior systems engineers noted that they see extreme impatience in younger members of the workforce. In organizations that have "high potential" programs, this sentiment was more common. Individuals frequently stated that the high potential individuals are told they are "the best" and "should be leaders" – which may create a false expectation about their ability and readiness to take on senior roles early in their careers. When these opportunities do not materialize in the first few years, junior systems engineers are more likely to leave the organization to seek these roles elsewhere.
- **Positional Stagnation** – several senior systems engineers noted that junior systems engineers often are pegged into small or limited roles and that it can be difficult to break free of these roles. For example, a younger systems engineer may become a "DOORS manager" (i.e. someone who manages the tool for tracking requirements). As they build skill in this role, they are so valued for this they are not given opportunities to grow beyond it. Some senior systems engineers noted that younger systems engineers have left because they wanted more diverse opportunities.
- **Work-Life Balance** – several senior systems engineers noted that younger systems engineers seem to prioritize a balance between work and home or social life. Therefore, younger members of the workforce who are asked to put in longer hours may choose to move to an organization that they feel will have more respect for this balance.

The team also looked at the differences between males and females in the sample. Figure 9 shows the organizational experiences across these groups.

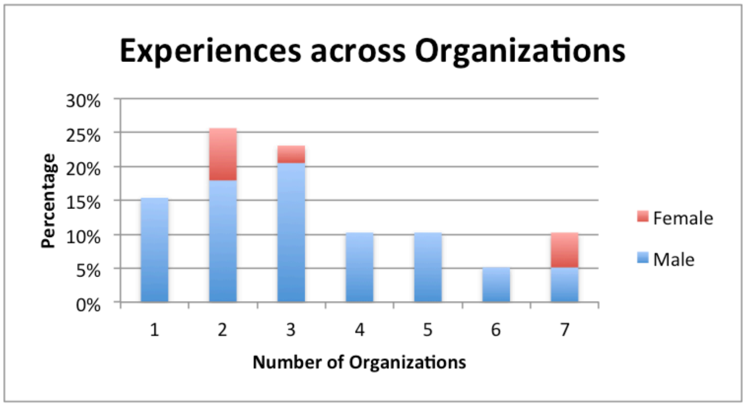


Figure 9. Breadth of experience across organizations by gender.

The strong majority of the sample in the current analysis is male; the sample size of females is too small to see any clear patterns at this time about movement through organizations by gender.

4.4.2 Experience by Types of Organizations

The Helix team is interested in the types of organizations individuals have experience at in addition to number. Ultimately, the team would like to include size, scope, mission, etc. of organizations in this analysis. Due to the limited number of interviewees and participating organizations in the current sample, in order to maintain the anonymity of the participating organizations, at this time it is only possible to provide insight into whether individuals have experiences in government, industry, or both. Figure 10 provides an overview by seniority.

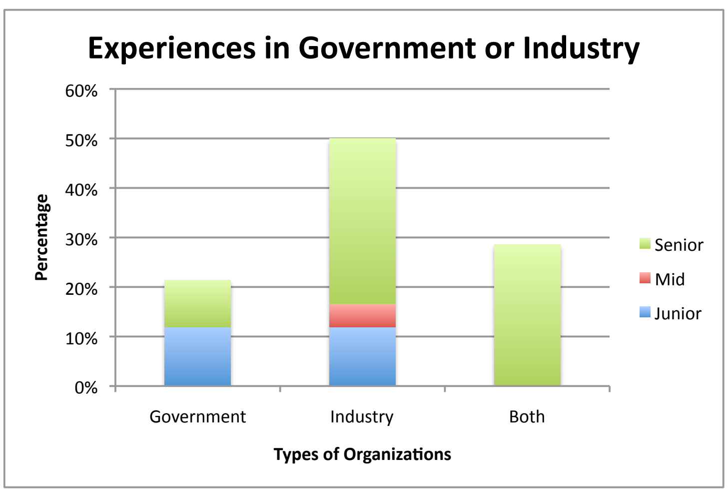


Figure 10. Percentages of the sample with experiences in government, industry, or both.

In the current sample, around 20% of individuals have only government experience, 50% have only industry experience, and around 30% have experience in both industry and government organizations.

Another way to view this information is not by percentage of the total sample but by the percentage for the individuals at each seniority level, as shown in Figure 11, below.

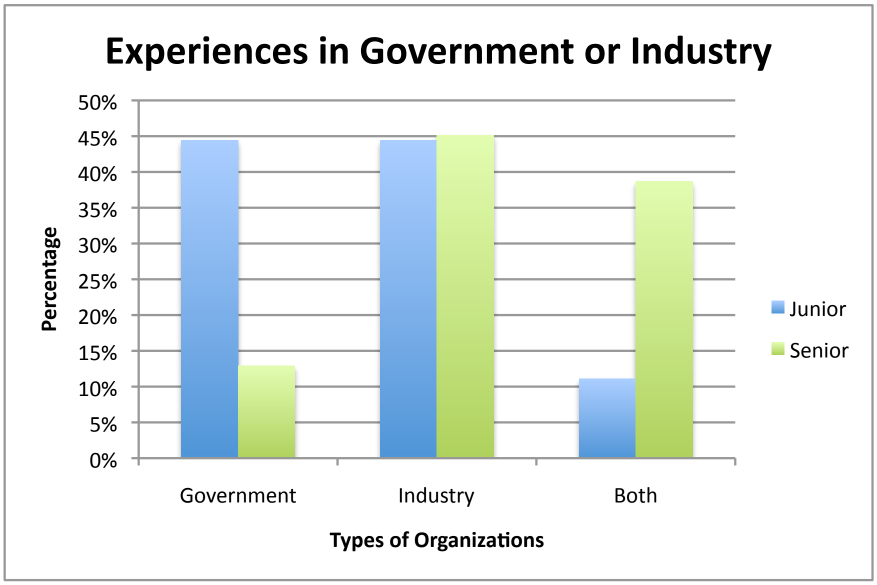


Figure 11. Percentages of seniority bands with experiences in government, industry, or both.

A few interesting findings include:

- Only one junior-level systems engineer has experience in both government and industry.
- Both mid-level systems engineers have only had industry experiences.
- Over 40% of the junior systems engineers have worked only in government; this is true for less than 20% of senior systems engineers.
- Of the roughly 40% of senior-level systems engineers who have had experience in both government and industry:
  - Four started in industry and moved to government. The individuals who started in industry and moved to the government have each indicated that they made this transition because, at the time, government positions were seen as more stable and secure.
  - Seven moved from government to industry. In follow up interviews, a few of these individuals cited increased opportunities as a reason for this transition.
  - A few had active duty military experience, worked in industry for a time, and returned to government.
- Of the roughly 40% of junior-level systems engineers who have experience in both government and industry, it appears that their moves between government and industry are primarily due to a desire to change to seek new opportunities, particularly additional responsibilities, by changing organizations.

Figure 12 provides a break down of government and industry experiences by gender.

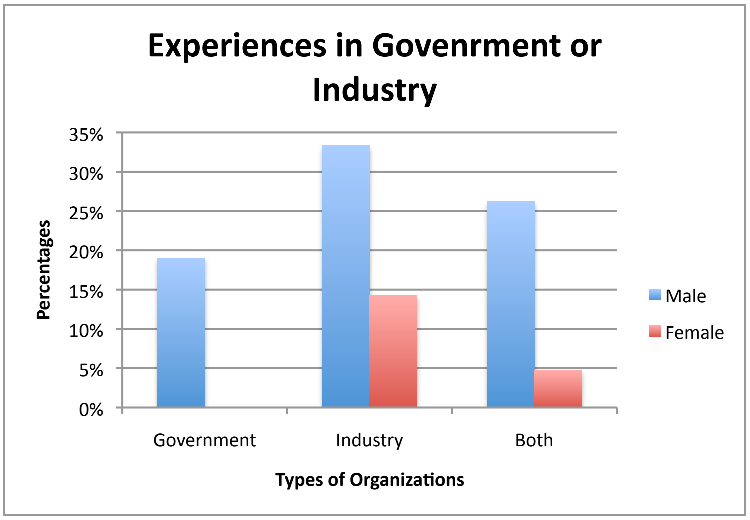


Figure 12. Percentages of the sample with experiences in government, industry, or both, by gender.

4.5 Experiences over the Systems Engineering Life Cycle

In both the initial and follow up interviews conducted to date, individuals have stressed the importance of experiencing different aspects of the systems life cycle in the maturation of systems engineers. To that end, the Helix team has examined the backgrounds of individuals in the current sample to determine how many areas of the life cycle they have experienced, which life cycle stages are most common, and in what order they were exposed to different stages of the life cycle. Because each organization has its own processes, many of which are proprietary, the Helix team has translated life cycle information into common terminology to protect the identities of participants and organizations and provide a mechanism for comparison across organizations. The team has used the *Guide to the Systems Engineering Body of Knowledge (SEBoK)* life cycle stages. The SEBoK provides an overview of each life cycle stage as well as specific information as the activities included (Pyster and Olwell 2013):

- **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. 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 systems engineering, 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 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. 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 discussion of orthogonal activities of systems engineers, labeled as "Systems Engineering Management", defined as managing the resources and assets allocated to perform systems engineering activities. Activities include planning, assessment and control, risk management, measurement, decision management, configuration management, information management, and quality management.

4.5.1 TOTAL EXPOSURE TO LIFE CYCLE PHASES

Based on the resumes and interviews with each individual, the Helix team recorded which stages of the life cycle an individual has experienced and in what order. The background information for the government systems engineers in the sample is very limited with regards to life cycle experiences, so the information presented below applies primarily to the industrial participants.

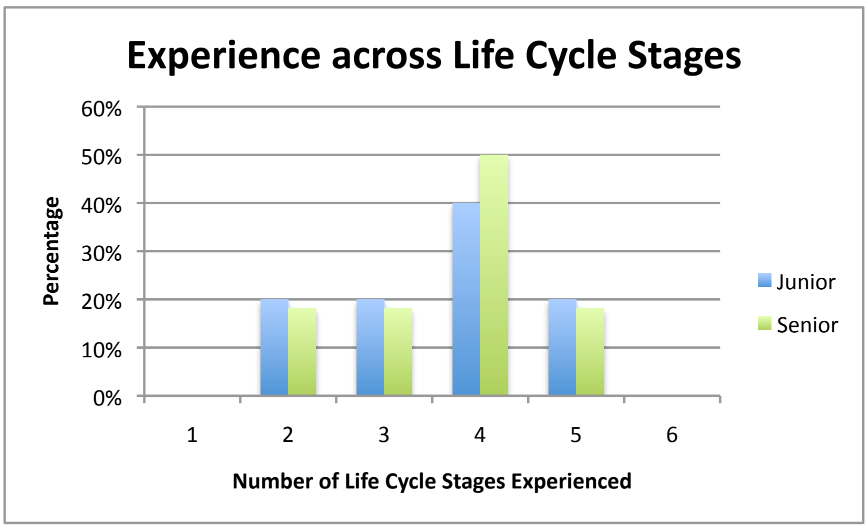


Figure 13. Breadth of experiences across the systems engineering life cycle stages.

Figure 13, above, provides an overview the total number of life cycle stages experienced; the percentages are of the individuals for each seniority, not of the whole sample. This gives an idea of the total breadth of the life cycle an individual has experienced. For example, a "1" would mean that the individual has seen only one aspect of the life cycle; a "6" would mean that the individual has experience in all five life cycle phases plus systems engineering management. The following are findings based on this analysis:

- 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.

- Likewise, none of the individuals in the current sample have experience in all five life cycle stages listed above plus systems engineering management. In the current organizational sample, most organizations were not heavily involved in modernization or disposal efforts. Therefore, this may change as the sample of organizations becomes more diverse.
- The majority (over 70%) 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.
- The junior systems engineers show a higher level of diversity in experiences across life cycle stages than expected. Over half of the junior systems engineers in the sample have already gained experience in four or five aspects of the life cycle. Several of the junior systems engineers interviewed participated in rotational programs for high potential systems engineers; therefore it is likely that the diversity across the life cycle is related to these rotational programs. The efficacy of these programs is unknown beyond the level of exposure provided.

4.5.2 ORDER OF EXPOSURE TO THE LIFE CYCLE

Though it is interesting to understand the diversity of life cycle stages experienced by systems engineers, it is perhaps more interesting to understand the order in which individuals experience these stages. Table 1 provides a very brief overview of the life cycle stages and the order in which individuals experienced that stage. For example, the column "First" shows that 3 individuals had Concept Definition as the first life cycle stage which they experienced in their careers; 16 had System Definition; 3 had System Realization, and so on.

Table 1. Overview of exposure to different stages of the systems engineering life cycle.

	Order of Exposure					
Stage	**First**	**Second**	**Third**	**Fourth**	**Fifth**	**Total**
Concept Definition	10%	10%	13%	20%	10%	63%
System Definition	60%	33%	0%	3%	0%	96%
System Realization	13%	40%	33%	3%	0%	89%
System Deployment and Use	10%	3%	13%	17%	7%	50%
Systems Engineering Management	10%	10%	13%	20%	10%	63%

This information is graphically represented in Figure 14, below.

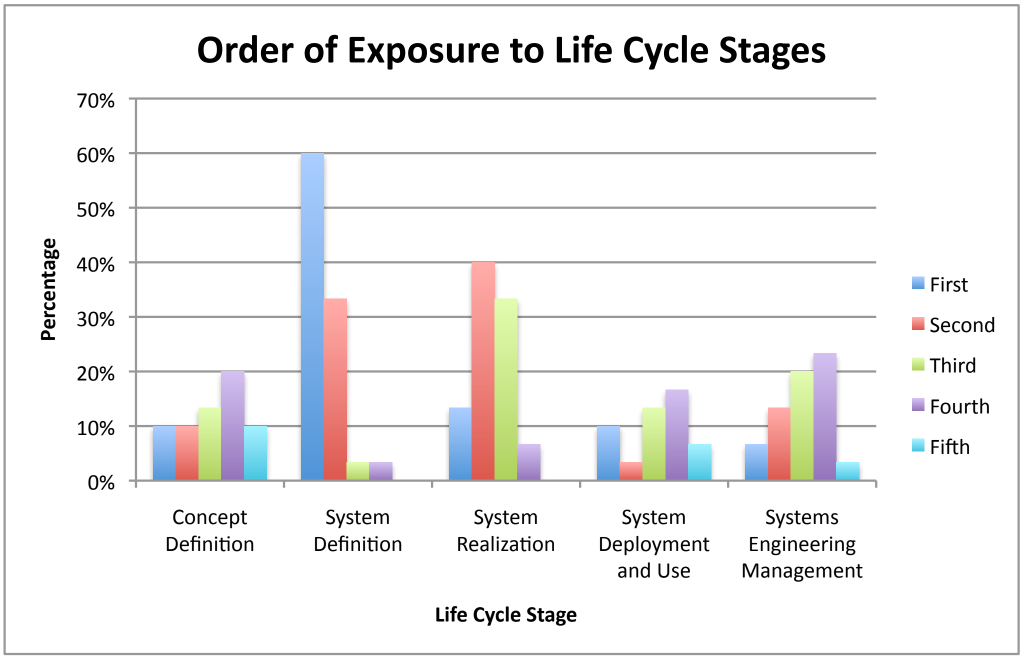


Figure 14. Order in which individuals are exposed to different stages of the systems engineering life cycle.

A few high-level observations include:

- Over 90% of the current sample is exposed to System Definition as either the first or second life cycle stage they experience. This aligns with the idea that the design of systems in a specialty engineering role is commonly a precursor to systems engineering work.

- Over 70% of the sample experience System Realization as either the second or third stage of the life cycle to which they are exposed. Many interviewees stated that understanding what was required to test as a system (a key activity in System Realization) was important for making systems engineers understand the consequences of early life cycle decisions. Therefore, it is seen as positive that a large percentage of the sample has some experience in this area.

For the individuals in the sample that provided this information, over 50% were first exposed to the System Definition stage of the life cycle. This stage includes some of the more traditional design activities (system requirements, architecture, and analysis) and as stated above, many individuals come to systems engineering after gaining experience in a traditional engineering discipline. It is therefore not surprising that many systems engineers gain initial exposure through System Definition activities.

System Realization, which includes traditional IV&V activities, is most commonly the second life cycle stage experienced by systems engineers. Second stage exposure is, however, not as clear-cut as first stage. About 35% of the sample has System Realization as the second life cycle phase to which they are exposed and about 30% experience System Definition second. Two of the individuals who experienced System Definition second (instead of first) began their careers in the military or other government service and experienced the operation and maintenance of systems before moving to industry to work on system development.

Around 40% of the sample had experience in System Realization as their third life cycle stage; about 30% had as their third 'life cycle' experience Systems Engineering Management.

Concept Definition was most commonly seen as the fourth life cycle stage to which an individual might be exposed. Of the individuals in the sample with experience in Concept Definition, over 70% were exposed to this as their third, forth, or fifth life cycle stage. As stated above, Concept definition includes business or mission analysis – which commonly is involved in proposal work – as well as stakeholder needs and requirements – the SEBoK differentiates between understanding stakeholder requirements and the development of system requirements, and that is reflected in this analysis. The activities in concept definition may involve direct interface with a customer and/or senior management within an organization. In the Helix initial and follow-up interviews, several senior systems engineers stated that it would be unusual for a very junior systems engineer to perform these activities, as it takes time to develop the skills necessary for successful customer interaction: listening, negotiation, and the ability to communicate back and forth between operational and technical data. It is not surprising that the majority of individuals with Concept Definition experience have generally performed these activities later in their careers. What is surprising is that for two of the chief systems engineers discussed in Section 4.3.1, concept definition was in fact the first stage in which they gained experience.

4.6 Program Types

One area where information is more readily available is in the types of programs being worked on. Currently, these include government acquisition programs (regardless of whether the individual worked for the government or industry at the time), commercial programs (without a defense application or customer), internal research and development (IR&D) programs; quick-reaction capability (QRC) programs (as differentiated from programs that follow the more typical government acquisition process), pursuits (which are often the precursors to programs, e.g. a response to an RFP), and special projects (which participants have explained are separate from IR&Ds, though the exact nature of these is not clear).

Experiences across these types of programs is shown in Figure 15. Note that in Figure 15, percentages are percentage at that level (i.e. percent of senior or junior, not percentage of the sample.)

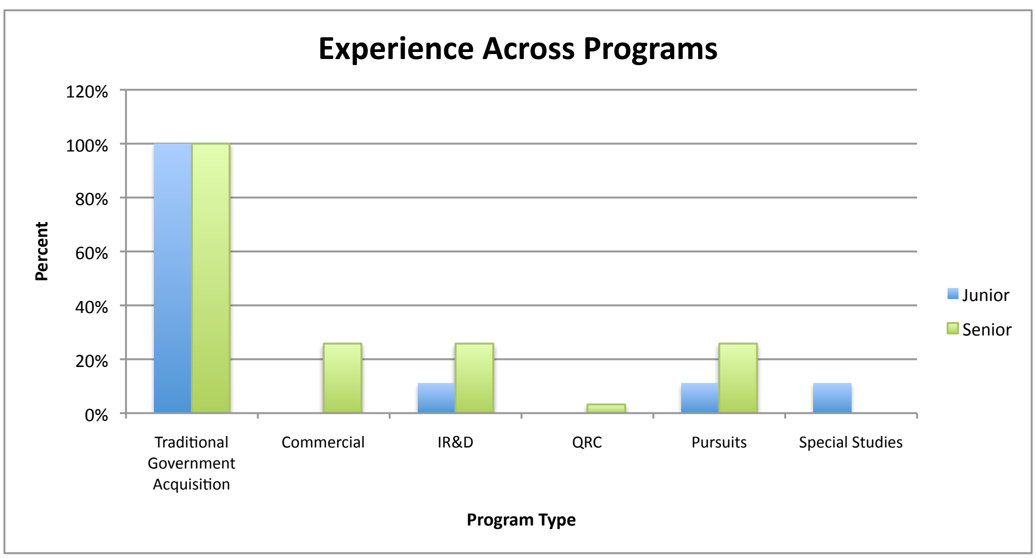


Figure 15. Types of programs worked on by each individual.

Because every individual in the sample is part of the DoD or DIB, it is expected that all individuals have experience in traditional government acquisition programs. A few findings based on this analysis include:

- No junior systems engineers in the sample have worked on purely commercial systems.
- Less than 10% of junior systems engineers have worked on IR&Ds. Of the junior individuals who have worked on IR&Ds, one was a member of a targeted development program for systems engineers within her company and the other self-identified as junior; this individual was initially identified as mid-level by the Helix team.
- In interviews, several senior systems engineers stated that they saw problems when younger engineers who had only experienced QRC programs had to transition to traditional defense acquisition programs. In that context, it is interesting that no junior engineers in the current sample have QRC experience.
- Pursuits are primarily conducted at the senior level. This is unsurprising as they are fast-paced and generally involve a very small team. It is worth noting that only about a quarter of senior engineers have reported participating in pursuit activities. The small percentage of junior systems engineers who reported working on pursuits were initially identified as mid-level by the Helix team and self-identified as junior.

4.7 Experience in Application Domains

Another aspect of an individual's career is the variety of domains in which they apply engineering or systems engineering practices and principles. The Helix team did not begin with an expected list of domains, but has catalogued domains as data has become available. Figure 16 shows the breakdown of domain experience for the current sample.

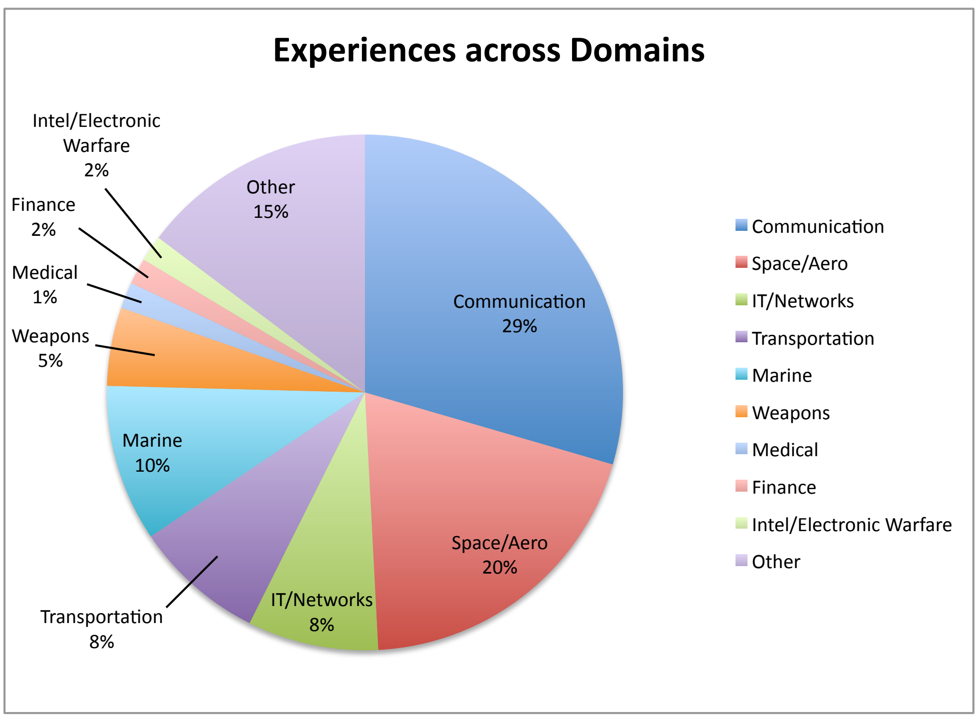


Figure 16. First cut of the breadth of domain experiences in the current sample.

No domain dominates. The domains include:

- Communications (both the communications components of larger systems and telecommunications),
- Space and Aeronautics,
- Information Technology (IT)/Networks (creation of computer systems, usually to support the business of a specific organization),
- Transportation (including automotive, ground vehicles, and rail),
- Marine (surface ship, submarine, etc.),
- Weapons systems,
- Medical devices,
- Financial services,
- Intelligence/electronic warfare systems, and
- Other (e.g. shipping, information management, consumer products such as printers, etc.)

The results in Figure 16 are relatively self-explanatory. One interesting feature is that 80% of the individuals with IT/network experience also had communications experience. This was the most significant overlap seen across domain experiences.

In the follow up interviews, several individuals who have experience in diverse domains were asked how that has helped them as systems engineers. Some stated that it is helpful to identify common principles that can be applied across all domains. Others stated that they have seen no differences in their roles between domains, so it does not appear to provide any specific advantage. The Helix team will further explore this in subsequent interviews.

4.8 Roles Played during Systems Engineers' Careers

The specific roles a systems engineer has played are an important aspect of his/her career. The identification of roles varies widely across the organizations currently included in the study. Therefore, the Helix team has to identify a common set of roles and apply these across the sample. The team began with Sheard's popular "Twelve Systems Engineering Roles" as a basis for consistently identifying the roles played by participants. (Sheard 1996) As the team conducted the analysis, however, it became clear that there were roles that may be important to the maturation of systems engineers that are not captured in Sheard's work because they are not "systems engineering" roles, per se. The roles identified in the current analysis are explained in Table 2. These roles are not presented in any priority order.

Table 2. Description of the roles used for analysis.

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

Sheard/ Helix	Role	Description
		development activities and helps to ensure that the system as designed should meet specification.
Sheard	**V&V Engineer**	Individual who plans and conducts verification and validation activities, such as testing, demonstration, simulation, etc.
Sheard	**Logistics/ Operations Engineer**	Sheard identifies this as an individual who performs the 'back end' of the systems engineering life cycle, who may operate the system, provide support during operation, provide guidance on maintenance, or help with disposal.
Sheard	**Glue**	Individual who is responsible for a holistic perspective on the system; from Sheard (1996), this may be the "technical conscience" or "seeker of issues that fall 'in the cracks'", particularly someone who is concerned with interfaces.
Sheard	**Customer Interface**	Individual who is responsible for coordinating with the customer, particularly for ensuring that the customer understands technical detail and that a customer's desires are, in turn, communicated to the technical team.
Sheard	**Technical Manager**	Individual who is responsible for controlling cost, schedule, and resources for the technical aspects of a system; often someone who works in coordination with an overall project or program manager.
Sheard	**Information Manager**	Individual responsible for the flow of information in a system development activity; specific activities may include configuration management, data management, or metrics.
Sheard	**Process Engineer**	Individual responsible for the systems engineering process as a whole, who likely has ties into the business directly.
Sheard	**Coordinator**	Individual responsible for coordinating amongst a broad set of individuals or groups who help to resolve systems issues; key associated skills would include negotiation, mediation, and communication.
Helix	**Organizational/ Functional Manager**	Individual responsible for the personnel management of systems engineers or other technical personnel in a business – not a project or program – setting. While this is not a "systems engineering" role, it does provide opportunities for individuals to build non-technical skills such as leadership and communication and is, therefore, included in the analysis for systems engineers.
Helix	**Instructor/ Teacher**	An individual responsible for providing or overseeing instruction of systems engineering discipline, practices, processes, etc. While not a "systems engineering' role, per se, an individual who provides training or education must have some level of mastery of the subject matter and has multiple opportunities to improve skills such as communication.

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

These roles are not completely orthogonal; it is possible for an individual to play multiple roles at any given time. Some roles are more related to specific activities of the life cycle – though these are also not totally orthogonal – while others include more considerations for soft skills. For one organization, the description of the responsibilities of a chief systems engineer (CSE) are such that a CSE is at minimum playing the roles of Glue, Customer Interface, Technical Manager, Information Manager, and Coordinator. A Requirements Owner might also be the Customer Interface as that person may be soliciting customer requirements as well as translating them into system requirements. For this initial analysis, the Helix team did not try to select a "most significant" role for any given time, but simply identified the roles that an individual has played over the course of his or her career.

This analysis was conducted in two phases: the first was a review of each individual's resume (or similar) to identify the exact titles used in their organizations. Where additional details on the activities for each position were provided, roles were also identified during this step. Where this detail was lacking, the team reviewed data from initial interviews and/or asked specific questions about roles in the follow up interviews. The initial results of this analysis can be found in Figure 17, below. The Helix team reviewed findings when possible in the follow-up interviews. Follow-up interviews have only been conducted with about half of these individuals, so it is likely that the team will be able to collect more data and verify the existing data for future analysis.

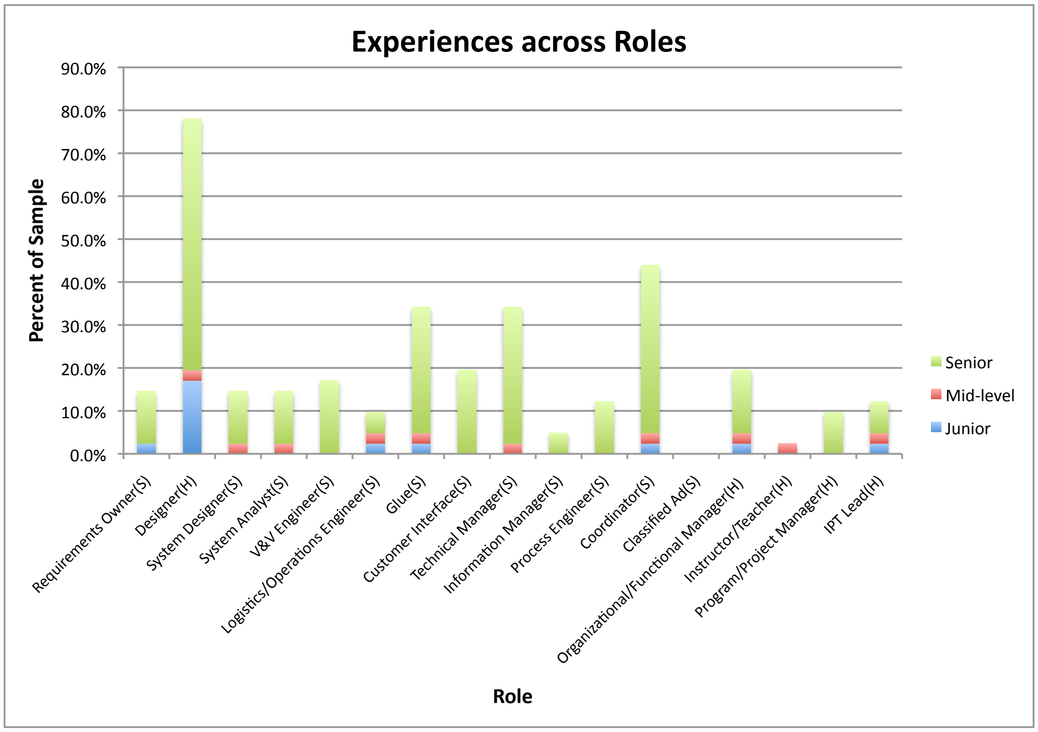


Figure 17. Experiences of systems engineers across a variety of roles, by seniority.

The most common role across seniority levels is Designer. This is unsurprising because, as previously stated, it is common for an individual to work as a specialty engineer performing some design functions at a lower level before becoming a systems engineer. It is surprising that not 100% of the sample is tagged as fulfilling this role; however, this may be due to the scarcity of the resume data for the government participants in the current sample and the group interview settings, which did not always allow a significant amount of time for detailed discussion of participant backgrounds. The Helix team will continue to explore this in follow up interviews.

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. It is therefore surprising that so few individuals have been identified as having played the role of Requirements Owner or V&V Engineer in their careers and more surprising that few of these individuals have been junior systems engineers. It also may indicate that there are titles that include requirements or V&V activities that are not obviously correlated. It is likely that as the data collection efforts continue, particularly as additional individuals are added to this analysis and follow up interviews continue, that this will change.

Most of the non-life-cycle-specific roles identified by Sheard – Glue, Customer Interface, Technical Manager, Information Manager, Process Engineer, and Coordinator – have primarily been played by senior systems engineers with more experience. It is interesting that the roles of Glue and Coordinator have also been played by a few junior systems engineers. This may indicate that these roles can be played on a smaller scale; for example, a junior systems engineer might provide coordination between a few disciplines for a component – a smaller scope than that of a chief systems engineer, but still providing a holistic view and helping to identify trade-offs.

Other non-technical roles, such as Customer Interface or Process Engineer – may 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.

The role of functional or business manager has been played by less than 20% of the sample and, unsurprisingly, primarily by senior systems engineers. A few of the senior systems engineers explained that they were required to become a functional manager for systems engineers as part of their organization's career path to becoming a senior systems engineer. Others stated that the moved into management but missed the focus on the technical and therefore transitioned back into a more technical role. The one junior systems engineer who has played this role played it in a logistics function prior to switching to a more technical field. However, as this still provided the opportunity to focus on leadership and communication skills, it was counted for this analysis.

As stated above, these results are preliminary. The Helix team expects that as additional follow up interviews are conducted, new data will be added to the current analysis and that as additional individuals are added to the analysis, this will give a richer picture of the types of roles individuals play and insight into overarching career paths.

4.9 Future Directions for Career Path Analysis

Going forward, the Helix team will collect and analyze additional data and work towards building a comparable, standardized career profile for each systems engineer in the sample.

4.9.1 Additional Data Collection and Analysis

As mentioned above, the Career Path Analysis is still evolving and the team is working to close gaps in the current data. For example, the Helix team would like to understand a wide scope of experiences related to systems and programs, including:

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

The hope is that, an understanding of the range of programs and systems that individuals have worked on, may provide a useful basis for comparison when considering current capabilities as well as providing direction for career planning. The types of data required to complete this analysis is sparse in the currently data set. In fact, with respect to system type and system level, only a few observations can be made:

- All individuals in the sample have worked on at least one product;
- All individuals in the sample have worked on at least a subsystem and system.

The Helix team is conducting follow up interviews and asking interviewees to review their career profiles and provide clarifications about their experiences with respect to these aspects of their careers.

Program size is another area for exploration. The current range of values is diverse: for the few individuals who have provided information on program size, teams range from 2-3 to over 1,000 and values from a few $100K to $10B. The Helix team hopes to provide insight into the roles of systems engineers relative to program size going forward. Some individuals have expressed concern about sharing the size of programs (either by size of the team or monetary value) that they have worked on, which may limit the ability of the team to collect this data.

4.9.2 END GOAL: COMPARABLE CAREER PROFILES

The Helix team plans to continue this analysis in the following ways:

- Complete this initial analysis for all individuals who have participated in the project (this analysis has been done for over 40% of the total sample to date);
- Work with individuals to validate career profiles in follow up interviews or through other means, including collecting additional information to fill gaps (e.g. program sizes, system types, system levels, etc.); and
- Perform this analysis with all new interviewees added to the project in Phase 4.

Once this analysis is completed, the Helix team will work on building master career profiles linked to current roles for the individuals in the study. If successful, this will allow comparisons between individuals in different roles or at different levels, and may be used to help determine potential next steps in a career path. For example, examine Figure 18, below.

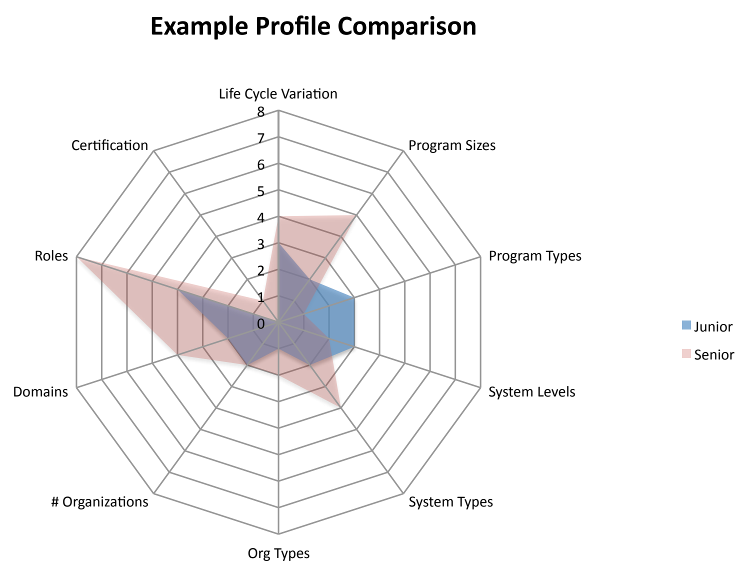


Figure 18. Example profile comparison.

In this example, various factors can be compared between two individuals. For example, it is clear that the senior individual (in red) has worked on a variety of program sizes, while the junior individual (in blue) has experienced a limited variety of program sizes. This may be important because size can to some extent determine program formality. If the junior systems engineer seeks to attain the role played by the senior systems engineer, this comparison might indicate that he/she should seek experiences on programs of different sizes.

This is a notional example of what may be built and the specific axes, the magnitude of these axes, and criteria used will likely change over time. However, the desire is that this sort of career path analysis can be generated for individuals and, when appropriate, may allow consistent comparisons. Currently, this is difficult to do across organizational boundaries; it is hoped that this methodology will allow more consistent discussions of issues across the community.

5. Towards the Theory: Mentoring

One of the three research questions being addressed by Helix is, “What are employers doing to improve the effectiveness of their systems engineers?” During the interviews, participants have discussed various organizational initiatives: some initiatives are effective and useful; some are perceived to be effective from an organizational point of view but are not from the employees’ perspective; some initiatives have been ineffective; and there are some other initiatives that are not in place but that employees think could be useful if implemented. In all the interviews, the organizational initiative that has been discussed the most is *mentoring*. This section summarizes the discussions on mentoring with 112 interviewees during 2013 (110 systems engineers and 2 human resources personnel), and follow-up interviews with 21 systems engineers during January – March 2014.

The findings reported in this section are based on a grounded theory based qualitative research approach. The qualitative analysis tool Dedoose was used to code portions of all interviews that were related to mentoring. Further coding was performed to identify themes and categories. These provided deeper insights into mentoring that have been summarized in the following sub-sections. It must be noted that the findings presented here are exclusively from Helix interview data only - no external data or perspectives have been added.

5.1 What is Mentoring?

Whenever mentoring was discussed during the interviews, the participants had their own internal definition of what that meant. Though an explicit definition of mentoring was neither provided nor explicitly established during the interviews, the interviewees’ responses collectively indicate the following characteristics of mentoring:

- Two individuals are involved in a mentoring arrangement: a Mentor and a Mentee (also referred to as a Protégé).
- The Mentor is usually “senior” when compared to the Mentee in age, experience, and/or expertise.
- Primarily, the Mentor “gives” and the Mentee “receives”.
- Mentor-Mentee relationship is a many-many relationship: A single Mentor can have multiple Mentees, and a single Mentee can have multiple Mentors – concurrently or spread over time.
- Mentor-Mentee interactions happen many times and extend over a period of time (from a few weeks to many years).

Some interviewees considered Mentors to be synonymous to subject matter experts (SMEs) who are consulted for their expertise on an as-needed basis only. When the Mentees in such cases are also senior systems engineers, this becomes more of a peer-peer relationship. Building such an “expert network” that can be tapped into when required is considered important for systems engineering; but some other interviewees expressed that such instances do not qualify as mentoring relationships. Another interviewee stated that observing an expert at work may provide useful learning, but also does not qualify as mentoring. One interviewee said that he had developed a course on a specific topic area in systems engineering, but not many signed up for it, so he refused to mentor somebody when the organization asked him to. To this person, teaching a course was equivalent to mentoring. Most other interviewees would have disagreed.

This conflict between what is mentoring and what is not mentoring has not been resolved in the findings presented here, since a common definition of mentoring was not established during the interviews. Therefore, whatever an interviewee considers to be "mentoring" is considered to be correct for the purposes of this report.

Murray (2002) defines mentoring as "a deliberate pairing of a more skilled or more experienced person with a lesser skilled or less experienced one, with the mutually agreed goal of having the less skilled person grow and develop specific competencies"; Shea (1994) defines mentoring relationship as a "developmental, caring, sharing, and helping relationship where one person invests time, know-how, and effort in enhancing another person's growth, knowledge, and skills, and responds to critical needs in the life of that person in ways that prepare the individual for greater productivity or achievement in the future"; and the word 'mentor' is defined by Merriam-Webster.com (2014) as "someone who teaches or gives help and advice to a less experienced and often younger person". Hence, even though a formal mentoring definition was not established during the Helix interviews, the characteristics of mentoring identified from the interview data align well with the definitions of mentoring found in literature.

In a subsequent publication, Murray (2006) indicates that there are some current mentoring practices in which "the mentor is not always older, a senior, and the protégé is not always younger, a junior", and that there are examples of mentoring between peers with different skill sets, and of mentors who are newer to the organization and younger. However, there were no such instances reported in the Helix interviews.

Literature also indicates some difference in terminology. In particular: Murray (2006) indicates that Mentors may perform several tasks in the process of their interactions with mentees, that include "coaching"; Rhodes and Fletcher (2013) use the terms "coaching" and "mentoring" to be synonymous; and Minter and Thomas (2000) complain that the terms "coaching", "mentoring', and "counseling" are frequently used interchangeably by researchers and authors as if they were synonymous concepts, and then go on to distinguish between them. It may be noted that during Helix interviews, no interviewee used the term "coaching" while discussing mentoring – either as a term synonymous to mentoring, or otherwise.

5.2 Types of Mentoring

Mentoring can be classified in a number of different ways. Participants frequently discussed two types of classifications during the interviews: the first was on the mentoring arrangement, particularly with respect to the role the organization; and the second was on the focus or content of mentoring.

5.2.1 Mentoring Arrangements

Broadly, interviewees described mentoring arrangements to be either Formal or Informal. But further analysis of the interview data revealed that, in addition, mentoring arrangements could also be acknowledged by the organization (Organization-Acknowledged) or the organization could be neutral (Organization-Neutral). This terminology was developed by the Helix team; it was neither used by the interviewees, nor was it found in literature on mentoring.

These four types of mentoring arrangements are described below:

- **Formal**: The organization plays an active role in establishing the Mentor-Mentee relationship, and also lays down guidelines for maintaining that relationship. Usually, organizations require that objectives and expectations for the Mentor and the Mentee be stated explicitly. The relationship and its progress tend to be monitored by the organization.

- **Informal**: The participating individuals establish the Mentor–Mentee relationship. Either a Mentor adopts a Mentee or a Mentee seeks a Mentor, and the relationship is established. Formal objectives or expectations are usually not stated explicitly, but it is considered good practice to establish these in some form at the start of the relationship. The organization does not play any active role here. It is up to the Mentor and the Mentee to drive the relationship.
- **Organization-Acknowledged**: The organization recognizes, encourages, monitors, and rewards a Mentor-Mentee relationship, irrespective of whether it is a Formal or an Informal arrangement. Naturally, all Formal relationships are also Organization-Acknowledged, but Informal relationships could also be Organization-Acknowledged. In some of the organizations, it is typical for Informal relationships to be featured in annual performance reviews of the Mentor.
- **Organization-Neutral**: The organization plays a neutral role here – it neither encourages nor discourages a mentoring arrangement; it does nothing to either establish a mentoring arrangement or to prevent one from being established. The Mentor/Mentee establish a relationship purely out of their mutual personal interests.

Table 3. Relationships between mentoring arrangements

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

The relationship between these four mentoring arrangements is illustrated in Table 3. As shown in the figure, all combinations are possible in an organization, except an Organization-Neutral - Formal mentoring arrangement.

5.2.2 Mentoring Focus

While discussing on what Mentees get mentored, interviewees distinguished between two types of mentoring: Career Mentoring and Technical Mentoring.

- **Career Mentoring:** The Mentor provides advice on career related issues: helps identify career goals and the paths leading to that goal. The Mentor could be from another group or division in the organization. The Mentor provides information about the organization: its culture, its procedures, and its policies. Mentees are groomed on management and leadership related topics.
- **Technical Mentoring:** The Mentor typically provides advice on the technical details of the system being engineered. The Mentor teaches lessons that are typically not found in textbooks and provides crucial insights on technical tools and processes. The Mentor also acts as a subject matter expert, answering any questions the mentees might have on the subject, the system, or the program.

5.3 Formal vs. Informal Mentoring

In all the mentoring related discussions, the biggest "debate" was on formal versus informal. Both these forms of mentoring have their own pros and cons, and in many cases, it appeared that the challenges and limitations in one were easily resolved by the other. Though the interviewees expressed their strong preferences, there was no clear "winner" nor was there meant to be one. Either of these could be effective, depending on the organizational policies and culture, or depending on the specific Mentor and Mentee involved. In any case, both Formal and Informal mentoring relationships have their place in any organization and in any Mentor-Mentee relationship. As one interviewee put it, "Its not about formal or informal as long as there is a commitment from me, the mentor, to spend the time to answer the questions, and commitment from [the mentee] to put some effort in". The views expressed by the participants are tabulated in Table 4, below.

Table 4. Comparison between aspects of formal and informal mentoring

Topic	Formal Mentoring	Informal Mentoring
Visibility to Organization	Organizations tend to have full visibility into the mentoring arrangement and how it is working out for the Mentor and the Mentee.	Organizations are usually unable to keep track of a mentoring arrangement and are sometime unaware that they exist.
Mentor-Mentee Pairing	Organizations enable the Mentor-Mentee pairing: in some cases it is forced and in some cases some flexibility in choice is given. There is the possibility of "wrong" selection or pairing that may not last long.	Mentors and Mentees tend to establish the relationship by themselves, usually upon the request of the Mentee. These relationships tend to last longer, since the Mentees have the flexibility to choose the Mentor that they are comfortable with.
Mentor Engagement	Not all senior engineers are good mentors; and not all potentially good mentors are willing to be one. If they are forced into a relationship against their preference, they tend to be ineffective and unwilling. "Some mentors don't interact at all," said one interviewee.	Mentors usually enter into a mentoring relationship by their own choice and therefore tend to be more engaged.
Mentee Responsibility	The organization plays a part in establishing a mentoring arrangement, and this works for introverted mentees. However, it could also make mentees more passive than active.	The mentees must find a Mentor and drive the relationship; "I think the mentee has to want it more than the mentor," said one interviewee. More introverted mentees may find it difficult to seek a Mentor and to ask them questions, while extroverted mentees find it easier to "go bug them and pick their brains".

Topic	Formal Mentoring	Informal Mentoring
Goals and Objectives	The organization lays down expectations for a mentoring relationship and could also provide guidance on establishing goals and objectives. This is helpful to the mentee in particular, and tends to be more impactful.	There may be an informal understanding of some overall goals and objectives between the mentor and the mentee, but there is no requirement to establish them.
Mentoring Load	Mentoring can be burdensome, mechanical, and obligating. It is possible to "go through the motions" without any beneficial engagement.	Mentoring is usually a pleasure for both the mentor and the mentee since they both tend to be "willing and eager". "If you try to formalize or institute a mentoring program it feels awkward" said one interviewee.

5.4 Benefits of Mentoring

In any typical mentoring arrangement, the Mentor "gives" and the Mentee "receives". Therefore, such an arrangement is most beneficial to the Mentee. However, there are benefits to the Mentors as well, that encourage them to engage in a mentoring relationship. In addition, the organization also stands to benefit. The discussions presented in this section also help establish the need for mentoring.

5.4.1 Benefits to Mentees

A Mentee is often a new or younger employee of the organization. Although Mentees may have formal education or training that qualifies them for their jobs, there is much to be learned in the context of the organizational environment and culture and in the nature of the systems being engineered. A Mentee could also be a senior engineer who is either new to the organization or has moved from another part of the organization, and his experience and expertise could be in a different discipline or system. In either case, the Mentee gains through Mentoring:

- **Relationship with Mentor**: The biggest benefit of mentoring to Mentees is the relationship they establish with their Mentors over the span of their career; most other benefits of mentoring are enabled through the Mentor. Mentors become the key enablers for Mentees: they look after them; they are their biggest advocates and champions; they help identify strengths; and they become critical factors for success in their careers. On the achievements he has accomplished, one interviewee said, "Without my mentor, it might not have happened." When asked what he would do differently if he were to re-start his career, one interviewee answered, "I would get a mentor."
- **Increased Personal Effectiveness**: Most interviewees identified mentoring as a critical factor that increases the effectiveness of systems engineers. The lessons that they learn and knowledge that they acquire through mentoring is less effectively attained through other means. Interviewees also noted that through mentoring, the learning is quicker and more effective when compared to other means.
- **Career Advancement**: Through their Mentors, employees often get exposed to opportunities within the organization that may not be visible otherwise. Mentors tend to point the Mentees in

the “right direction” and enable them to move in that direction. In hindsight, such moves have been significant contributors for the career advancement of many interviewees.

- **Critical Lessons**: During mentoring, Mentees often receive important lessons from their Mentors, which have made a significant impact in their careers. Many interviewees quoted their mentors during the interviews; and how something they learned from their mentors shaped their perspectives. Mentees also learn how to cope with challenges, how to deal with complexity, and also receive tactical guidance from Mentors on “how to do this job well.” Mentees also acquire critical insights into the system or program that help them over their career.
- **Strong Networking**: Building a strong professional network is key to any employee. Through mentoring, Mentees get exposed to many senior engineers and others in the professional network of their mentors.

5.4.2 BENEFITS TO MENTORS

A Mentor is usually a senior, experienced engineer who has spent more time in that part of the organization into which the Mentee has entered, or in dealing with the type of system that may be unfamiliar to the Mentee. Though the Mentee stands to benefit the most, the Mentor also benefits from mentoring.

- **Professional Gratification**: “If I can get people to do better at what they’re doing, that’s an incentive for me to stick around” said one interviewee; “I mentor people just because I want to,” said another. Many considered mentoring to be an important part of their jobs, irrespective of the organizational acknowledgement of it. “Helping the stars” and “ teaching the young’uns what to do” seems to be motivation enough for the Mentees. One interviewee even said, “their work portrays my effectiveness”, about those he mentors.
- **Organizational Recognition**: In organizations where mentoring is acknowledged, Mentors get recognized for their efforts. It is also typical for mentoring to be featured in the annual performance reviews of the mentors. Being a mentor increases the visibility of an employee within the organization and also helps in career advancement.
- **Reduced Workload**: Some Mentors considered mentoring to be a means of reducing their workload. When a mentee is able to share the load, “I don't have to work as many hours,” said one interviewee.
- **Groom Successor**: An interviewee said that an important lesson that his mentor had taught him was that “you can’t advance [in your career] without training a person to replace you” and that by following that advise, he has been presented with lots more opportunities than his peers. “Somebody’s got to take over” the Mentor’s role and responsibilities in the organization – not just after retirement or after moving on to a different job, but also in the absence of the Mentor. One interviewee had met with an accident and had to stay away from work for a few months during recovery. Since he had previously mentored someone, that person was able to fill the gap during his absence on the job.

5.4.3 BENEFITS TO ORGANIZATION

Effective mentoring not only benefits the Mentees and Mentors involved in the relationship, but also the workforce as a whole. When this happens, the organization at large benefits as well. One of the early motivations of the Helix study was the concern that a significant number of senior systems engineers would soon be eligible for retirement and whether the organization would be able to effectively manage the gap that would be created. Mentoring is considered to be an effective way to help address this gap.

- **Gain Effective Knowledge Transfer**: When senior engineers retire, they typically take along with them many years' worth of valuable experience and expertise, and this is a concern for any organization. Among various knowledge transfer mechanisms that organizations typically deploy, interviewees indicated that mentoring is very effective. In a couple of scenarios, organizations had budgeted time for documentation but interviewees agreed that it was not a good decision and that mentoring would have been more effective. In one organization, interviewees felt that the organization was effectively handling the workforce situation (of retiring senior engineers) by including Mentoring as part of the transition plan in the workforce.
- **Identify High-Potential Engineers**: Through the feedback from Mentors, organizations can identify high-potential engineers who are being mentored. These young engineers could then be placed on a fast track or experience other organizational initiatives that would mature them faster into the next generation experts and leaders.
- **Reduce Orientation Time**: When employees enter a new organization or department, irrespective of their educational and work background and experience, it takes some effort by the organization and by the individual before they can become productive and effective in their new roles. Most often, individuals spend a lot of time figuring out things by themselves, and in searching for the information and organizational procedures required to do their jobs. In these cases, effective mentoring can significantly reduce the time taken for such employees to get oriented to their jobs.
- **Fill Workforce Gaps**: When senior engineers retire, mid-level engineers most effectively fill the gap created and in many organizations there are not enough mid-level engineers. Through mentoring, such emerging workforce gaps can be filled proactively. In other situations, there exist some "less sought after" jobs in an organization that are still important, e.g. test engineer. While talking about his job, one interviewee mentioned, "you would be surprised how many people don't want to do this job!" This could be due to a combination of organizational culture or misconception about what that job entails. Again, mentoring is an effective way to fill such workforce gaps that may not be filled easily otherwise.
- **Increase Employee Retention**: "Today, employees do not stay on with companies as long as they used to," said one interviewee. When younger employees leave, they also take along with them the learning and knowledge that they have acquired, and the organization stands to lose. When employees are recognized by the organization for their potential, when the organization and seniors invest time and effort on them, and when their work is deemed important, it significantly increases the loyalty of those employees towards their job and the organization. Mentoring helps increase such employee loyalty and thereby employee retention.
- **Improve Organization Culture**: Mentoring builds relationships and teams, naturally. It promotes a healthy environment where senior engineers are willing to share and teach, and junior engineers are recognized and encouraged. This creates a positive organizational culture that all employees are happy to be a part of. In one organization, "there a number of people that are willing to help somebody – not 10% but 90% of the workforce. It is just part of the culture" said one employee.

5.5 IMPORTANCE OF MENTORING FOR SYSTEMS ENGINEERS

Mentoring, in general, is helpful to any Mentee in any organization – and not just for engineers. However, in the context of systems engineers and systems engineering, Mentoring plays a particularly important role.

- **Systems Engineers Can be a Rare Commodity**: In some organizations, there are not enough systems engineers to perform the required SE activities. In such cases, mentoring is an effective way to fill the pipeline of systems engineers, especially when there is likely to be a gap with the retirement of senior systems engineers. "There are not [as] many systems engineers as I thought," said one interviewee, "without mentoring there will be a loss".
- **Identifying and Recruiting SE talent**: In many organizations recruitment directly into the systems engineering division or into a systems engineer's role does not happen. Systems engineers are brought in from other parts of the organization. In these cases, mentoring plays a crucial role where Mentors help identify potential systems engineers and play the role of an advocate for SE to encourage them to join systems engineering.
- **Support for New Systems Engineers**: As one participant said, "It isn't rare and it isn't uncommon to end up doing systems engineering if you were not a systems engineer before". In most organizations, this is a common way for recruiting systems engineers. So when non-systems engineers enter SE, mentoring plays a key role in equipping them to be effective systems engineers.
- **Changing Face of Systems Engineers**: Systems engineers used to be "greybeards" who "floated up to the top and had all the experience". But today, depending on organizational policies and practices, engineers may become systems engineers without a lot of experience. Mentoring becomes a critical initiative that could equip such systems engineers to be effective in their jobs.
- **Nature of Systems Engineering**: "As much as we like the young engineers to act as systems engineers, it's difficult for them to understand how our different taskings are integrated across," said one interviewee. "There's a big gap between young engineers and old experienced people with a lot of tribal knowledge" said another. Due to the nature of systems engineering, and particularly how it is performed in the organization, there is much to be learned hands-on that cannot be learned before entering the organization. Though education does help, it is not sufficient in most cases. One interviewee elaborated, "I had the advantage as a teenager, some of my mentors had been doing the work since the 1950's and they were about ready to retire. They were solving incredibly complex problems without computers, without high-end sensors. They had to really understand what they were doing and really have clever ways of solving the problem. So they really kind of passed on that skill set that you don't learn in college."

5.6 CRITICAL FACTORS FOR SUCCESS WITH MENTORING

Though mentoring is considered to be an effective solution to address the gap that could be created by an aging retiring workforce, just the existence of a mentoring arrangement, either formal or informal, by itself does not guarantee success. However, there are factors that significantly influence the success or failure of any mentoring arrangement, and interviewees provided a number of anecdotes and personal experiences to elaborate on this. Recognizing and addressing these factors by the organization and the individuals involved could prevent failure and could vastly increase the chances of success with a mentoring arrangement.

- **Mentoring Has Its Limitations**: Mentoring does not always work in all organizations, for all employees; mentoring does not work in isolation, but in conjunction with other organization initiatives to support its employees, such as training and education; and mentoring cannot be solely relied on for knowledge capture from a retiring senior engineer. Even with respect to Mentees, who stand to benefit the most in a mentoring arrangement, one interviewee stated, "I do not see different traits among those formally mentored, informally mentored, and not mentored at all." While there are many cases that would prove this statement wrong, it only shows that mentoring is not a universal solution. One interviewee stated "I've seen great systems people that have no formal mentoring" – it shows that while mentoring is highly desired, it is not essential for everyone. Another interviewee supported this view when he said "I'm proof that [mentoring] is not essential. It just made it more uncomfortable for me."
- **Right Choice, Right Pairing**: Ineffective mentors exist, and just the fact that someone is a true expert with many years of experience does not automatically make them a Mentor candidate. As one interviewee elaborated, "some are good with sharing their knowledge, and there are people who don't want to share any of their knowledge". Similarly, not everyone benefits from being a mentee; some are more comfortable learning things on their own than from a mentor. Finally, it is most important to pair the right Mentor with the right Mentee – alignment between them is important; "[mentoring] is a two way street", and it can become a "life long relationship".
- **Balance between Formal and Informal Mentoring**: While most interviewees had a personal preference for informal mentoring, everyone agreed that a bit of formality does help. Therefore, establishing the right balance between formal and informal mentoring by the organization is critical. As discussed in the section on "Formal vs. Informal Mentoring", there are some aspects of mentoring that benefit from a formal arrangement – such as establishing goals and objectives, and keeping track of mentoring arrangements. But for aspects such as deciding the right mentor-mentee pair and for driving the frequency and nature of the interactions, it is advantageous to let those be informal.
- **Mentor Training**: Mentors may possess the experience and expertise that mentees stand to benefit from, but they need some guidance on establishing and sustaining a mentoring relationship – it does not come naturally to all mentors. Providing some guidance on how to establish goals and objectives for mentoring, and on how to balance teaching and guiding (for self learning by mentees) would be beneficial to mentors. In one organization, interviewees mentioned that there a mentoring manual, but it was very dated, and that currently mentoring happens in a more ad-hoc manner.
- **Make Mentoring Visible**: If any mentoring program (formal or informal) is officially acknowledged by an organization, it must also take the effort to make it known to all its employees. In some organizations, the interviewees were not aware if their organization had a mentoring program. In some cases, top management initiated a mentoring program that failed to percolate through the organization to reach the potential mentors and mentees. One interviewee said, "I didn't even know we had mentors until someone gave me a mentee."
- **Mentoring Needs Time**: Benefits of mentoring cannot be reaped instantaneously – in some cases, it is only after a number of years that mentees benefit from the mentoring that they had early on in their careers. Similarly, mentoring cannot be a last minute activity that a retiring senior engineer is expected to do in the remaining months or weeks of employment – any mentoring done is not likely to be very effective. With many other activities taking priority

before retirement, there is usually not enough time mentoring. Mentoring cannot be rushed, even from the perspective of the mentee who cannot be expected to "think of all your questions today."

- **Load on Mentor**: Organizations must always be aware of the load mentoring places on the Mentor – they cannot be expected to do everything that they are responsible for and also do mentoring. One interviewee said that he decided not to mentor people "as much as I should or could". At the same time, mentoring cannot be a fill-in activity where a mentor is told, "you are not busy this month – so go mentor this person."
- **Back up a Mentoring Program**: In one organization, a formal mentoring program was rolled out where everyone would have a mentor and a mentee. It was formal. But "it wasn't backed by a lot of horse power", as noted by an interviewee. The organization needs to back up a mentoring program with the required budget and time for the mentor and mentee to engage in a relationship – it is dangerous to establish a mentoring program just to claim that one exists. Breaking a mentor-mentee relationship can also be harmful – such break ups could happen for a number of reasons, but if it is something that an organization could prevent, it should.

5.6.1 Broad Recommendations to Organizations on Mentoring

The observations and findings from the Helix interviews on the topic of mentoring have been presented in the preceding sections. Particularly, this section lists critical factors that an organization should consider, to increase the chances of success with mentoring. In summary, key recommendations to organizations on mentoring are presented here, depending on the current state of mentoring in the organization.

- **No Mentoring Initiative**: It is strongly recommended that a mentoring initiative be Acknowledged by the organization. It is not essential that a Formal mentoring initiative be initiated, but rather an encouragement for Informal mentoring, with some formality to provide structure and support.
- **Challenges with Formal Mentoring Initiative**: If the organization is not having enough success with its current formal mentoring initiative, it is recommended that the organization review the current initiative keeping in mind the critical factors identified above. It is possible that the reducing the level of formality, ensuring right mentor-mentee pairing, and increasing organization support for implementation would improve the effectiveness of the mentoring initiative
- **Successful Mentoring Initiative**: While this is a good scenario for an organization to be in, it is recommended that the organization understands the causes for this success. Over time, there could be many changes including retirement of current mentors, budget constraints that would limit the time and support for mentoring, re-structuring within the organization, and mergers / acquisitions of the organization. In such cases, it is important for the mentoring initiative and its success to be sustained.

6. FUTURE DIRECTION

There will be serveral new directions for the Helix project in Phase 4, which runs from April through November 2014. These will provide opportunities for validation, for expansion to a wider population of systems engineers, and for collection of perspectives from the wider community about the value of systems engineers, as described below.

6.1 HELIX WORKSHOPS

The Helix team plans to conduct a workshop in Phase 4. The objectives of this workshop will be to gather alternative views, to provide additional means of data collection, to gain a sanity check on the collected data, to gain insight on the analysis approach, and to validate Helix findings.

Tentatively, during the workshop, there will be:

- Conversations on the current seniority designations for systems engineering (junior, mid, senior) and the criteria used for developing these designations
- Review and feedback on a model of career progression for systems engineers
- Review and feedback on a model of experiences for systems engineers
- Review of systems engineering competencies and how current competency work may align with the Helix models.

The workshop participants will be selected in advance based on their potential insights into these matters. Currently, the Helix team plans to conduct this Workshop in summer 2014, and anticipates conducting more in future, depending on the success and value obtained from this first workshop.

6.2 ADDITIONAL DATA SOURCES

The primary mode of data collection for Helix thus far, has been through face-to-face interviews at an organization, with follow-up telephone interviews. In addition, during Phase 4 of the project, the Helix team expects to collect data from additional sources as well.

6.2.1. INCOSE CERTIFICATION DATA

Through a Memorandum of Understanding with INCOSE, the Helix team expects to receive applications, resumes and other documents submitted by systems engineers from around the world, seeking professional certification from INCOSE (e.g. Certified Systems Engineering Professional-CSEP). Currently, application data from over 2000 applications is available, with hundreds being added annually. During Phase 4, the Helix team will cleanse the data, build a comprehensive database, and report preliminary findings on the demographics and characteristics of the applicants. The reports will be aggregated, without revealing the identity of the individual applicants or their organizational affiliations.

6.2.2 NEW TYPES OF INTERVIEWEES

Helix interviews during Phase 1-3 have been exclusively with interviewees from participating organizations. The Helix team proposes to expand the data collection during Phase 4 by conducting interviews with systems engineers who operate as independent consultants, and are currently not affiliated to any organization. It is expected that these individuals will be senior systems engineers who will have spent considerable time in many systems engineering roles with one or more organizations over their careers. Again, the identities of these individuals will be protected in the Helix reports, and their commitments to the organizations they consult for (at present or in the past) will be honored.

6.3 Theory of Systems Engineers

As described in Section 3, a goal for the Helix project is to develop a theory of systems engineers. This will provide a data-driven model that can be used for career planning at the individual or organizational level or to support workforce development planning. The development of a first substantial draft (version 0.25) of this theory is expected to be a key focus of Phase 4 of the project.

7. References

Adcock, R., A. Pyster, J-C. Roussel, D.D. Walden, W.D. Miller, K. Forsberg. 2012. "What is the Value of the SE Body of Knowledge for INCOSE and SE?" International Council on Systems Engineering (INCOSE) 22nd Annual International Symposium, July 9-12, 2012, Rome, Italy.

Anderson, C. 2010. "Presenting and Evaluating Qualitative Research." *American Journal of Pharmaceutical Education.* 74(8): 141.

Boehm, B., J. Bayuk, A. Deshmukh, R. Graybill, J.A. Lane, A. Levin, A. Madni, M. McGrath, A. Pyster, S. Tarchalski, R. Turner, and J. Wade. 2010. *Systems 2020: Strategic Initiative*. Hoboken, NJ: Systems Engineering Research Center (SERC). SERC-2010-TR-009.

Creswell, J.W., C.V.L. Plano. 2011. *Designing and Conducting Mixed Methods Research*. 2nd ed. Thousand Oaks, CA: Sage.

Davidz, H.L. and D.J. Nightingale. 2007. "Enabling Systems Thinking to Accelerate the Development of Senior Systems Engineers." *Systems Engineering*. 11(1).

DoD. 2013. "SPRDE Functional Career Field: Critical Acquisition Workforce Data FY 2013-Q3 (as of June 20, 2013)." U.S. Department of Defense, Office of the Undersecretary of Defense for Acquisition, Technology, and Logistics (OUSD (AT&L)). 30 June 2013.

Ferris, T., D. Prun, K. Geist, A. Chia, P. Jackson, R. Freeman. 2011. "Graduate Reference Curriculum in Systems Engineering." International Council on Systems Engineering (INCOSE) 21st Annual International Symposium, June 20-23, 2011, Denver, CO, USA.

Frank, M. 2006. "Excellence in Systems Engineering: What Characterizes Successful Systems Engineers?" (paper #106). Conference on Systems Engineering Research (CSER), April 7-8, 2006, Los Angeles, CA. 1-10.

Frank, M., K. Frampton, and T.D. Carlo. 2007. "Characteristics of Successful Systems Engineers, Systems Architects and IT Architects." Asia-Pacific Software Engineering Conference (APSEC), Nagoya, Japan. 1-12.

GAO. 2008. *Defense Acquisitions: Assessments of Selected Weapon Programs*. Washington, D.C.: Government Accountability Office (GAO). GAO-08-467SP.

———. 2011. *Weapons Acquisition Reform: Actions Needed to Address Systems Engineering and Developmental Testing Challenges*. Washington, D.C.: Government Accountability Office (GAO). GAO-11-806.

———. 2012. *Weapons Acquisition Reform: Reform Act Is Helping DOD Acquisition Programs Reduce Risk, but Implementation Challenges Remain*. Washington, D.C.: Government Accountability Office (GAO). GAO-13-103.

Goulding, C. 202. *Grounded Theory: A Practical Guide for Management, Business and Market Researchers*. Thousand Oaks, CA: Sage.

INCOSE. 2010. *Systems Engineering Competencies Framework*. San Diego, CA, USA: International Council on Systems Engineering. INCOSE-TP-2010-003.

INCOSE. 2012. *Systems Engineering Handbook: A Guide for System Life Cycle Processes and Activities*, version 3.2.2. San Diego, CA, USA: International Council on Systems Engineering (INCOSE), INCOSE-TP-2003-002-03.2.2.

INCOSE Technical Operations. 2007. *Systems Engineering Vision 2020*. San Diego, CA, USA: International Council on Systems Engineering. INCOSE-TP-2004-004-02.

"Mentor." 2014. Merriam-Webster.com. Accessed April 16. http://www.merriam-webster.com/dictionary/mentor.

Minter, R.L. and E.G. Thomas. 2000. "Employee Development through Coaching, Mentoring and Counseling: A Multidimensional Approach." *Review of Business* 21(1/2): 43–47.

Murray, M. 2002. *Beyond the Myths and Magic of Mentoring: How to Facilitate an Effective Mentoring Process*. John Wiley & Sons.

Murray, M. 2006. "Innovations in Performace Improvement with Mentoring." In *Handbook of Human Performance Technology.* San Francisco: Pfeiffer, 455–77.

PMI. 2012. *PMI Lexicon of Project Management Terms*, Version 2.0. Newton Square, PA: Project Management Institute (PMI).

Pyster, A., D.H. Olwell, T.L.J. Ferris, N. Hutchison, S. Enck, J. Anthony, D. Henry, and A. Squires (eds.). 2012. *Graduate Reference Curriculum for Systems Engineering (GRCSE™)*. Hoboken, NJ, USA: The Trustees of the Stevens Institute of Technology. Available at: www.bkcase.org/grcse/.

Pyster, A., R.L. Pineda, D. Henry, N. Hutchison. 2013. *Helix – Phases 1 and 2.* Hoboken, NJ: Systems Engineering Research Center, Stevens Institute of Technology. SERC-2013-TR-038-2.

Rhodes, C. and S. Fletcher. 2013. "Coaching and Mentoring for Self-Efficacious Leadership in Schools." *International Journal of Mentoring and Coaching in Education* 2(1): 47–63.

Shea, Gordon F. 1994. *Mentoring : Helping Employees Reach Their Full Potential*. New York: AMA Membership Publications Division, American Management Association.

Sheard, S. 1996. "Twelve Systems Engineering Roles." Proceedings of the International Council on Systems Engineering (INCOSE) Sixth Annual International Symposium, Boston, MA.

Torelli, N. 2012. Presentation as part of Pyster, A.; Torelli, N.; Madni, A.; Hanneman, L.; Highland, F. 2012. "Systems Engineering Degrees and Certificates: What is the Right Mix for Industry and Government?" *National Defense Industrial Association (NDIA) 15th Annual Systems Engineering Conference*, October 22-25, 2012, San Diego, CA.

Welby, S. 2011. "DoD Systems Engineering: Status Report." National Defense Industrial Association (NDIA) Systems Engineering (SE) Division Meeting, Washington D.C. Metropolitan Area, USA. 1-33.

Welby, S. 2010. "DoD Systems Engineering Update." National Defense Industrial Association (NDIA) Gulf Coast Chapter: 36th Air Armament Symposium, Fort Walton Beach, FL, USA. 1-25.

8. Glossary

Acronyms & Abbreviations

Acronym/Abbreviation	Meaning
CSE	Chief Systems Engineer
DASD(SE)	US Deputy Assistant Secretary of Defense for Systems Engineering
DIB	Defense Industrial Base
DOD	US Department of Defense
HAP	Helix Advisory Panel
INCOSE	International Council on Systems Engineering
IPT	Integrated Product Team
IR&D	Internal (or Independent) Research & Development
IRB	Internal Review Board
IT	Information Technology
IV&V	Integration, Verification, & Validation
MBA	Master of Business Administration
NDIA-SED	National Defense Industrial Association – Systems Engineering Division
PEO	Program Executive Office
QRC	Quick Reaction Capability
SERC	Systems Engineering Research Center
SEBoK	*Guide to the Systems Engineering Body of Knowledge* (Pyster and Olwell 2013)
SME	Subject Matter Expert
SPRDE	Systems Planning, Research, Development, and Engineering
UARC	University-Affiliated Research Center
V&V	Verification & Validation

Terms

characteristic – a feature or quality belonging to a systems engineer and serving to identify systems engineers as a group; it is not about what the systems engineer knows or can do (see ***competency)***.

chief systems engineer – Individual responsible for the technical aspects of a program, who actd across the program life cycle and provides coordination and, when necessary, negotiation across a number of engineering specialties to develop a system solution and an appropriate process to realize that solution. The CSE often has direct interaction with the customer as well as oversight of other systems engineers and/or engineering personnel within a program.

competency – Knowledge of and skill in the practices required for successful development of a system. There are 3 types of relevant competencies for Helix:

- Technical competency – competency relevant to a specific technical discipline or domain, e.g., electrical, mechanical, or civil engineering disciplines or the telecommunications, engines, or ship domains
- Systems engineering competency – competency relevant to the process, methodologies, tools, or concepts of systems engineering
- Business competency – knowledge and skill in navigating the specific workings of the organization in which one works

effectiveness – The degree to which systems engineering activities have a positive impact on the outcomes for a system. For example, an individual systems engineer is effective when the outcomes for which he/she is individually responsible are achieved as a result of the systems engineering activities he performs and an organization's systems engineering workforce is effective when the outcomes for which they are collectively responsible are achieved as a result of the systems engineering activities they perform.

experience – Participation in or observation of activities during which an individual is afforded the ability to learn.

- Professional experience is direct observation of, participation in, or leadership of activities in a work environment.
- Academic experience includes any activities that occur within an educational setting and generally will include formal classroom activities such as participation in a degree program.
- Social experience is any life activity (outside the classroom or professional setting) that is relevant to the effectiveness of systems engineers.

Notes: The Helix team focuses on professional and academic experience, but does collect information on social experience when provided. In general, the Helix team focuses on suites of experiences rather than a single, isolated experience.

systems engineer – An individual who performs systems engineering activities and is recognized (either formally or informally) by his or her organization for their ability to perform these activities.

systems engineering – An interdisciplinary approach and means to enable the realization of successful systems. It focuses on defining customer needs and required functionality early in the development cycle, documenting requirements, then proceeding with design synthesis and system validation while considering the complete problem. (INCOSE 2012)

APPENDIX A – FOLLOW UP TEMPLATE/QUESTIONS

Interview Information
Organization:
Individual:
Original Interview Date:
Follow-up Interview Date:

Resume/Background
- [insert highlights from background]

- Q: Has your role changed since your first interview? If so, can you please describe your current role?
- Q: Do you consider yourself a junior, mid-level, or senior systems engineer? [Does this align with assessment from profile?] Why do you believe this? What will it take you to transition to next level SE?
- Q: How long you have been a systems engineer? What do you consider your first SE role?

Notes from First Interview
- [Insert any relevant notes from first interview; identify any specific questions from first interview responses]

Follow Up Questions

General Questions (all)
- Q: Do you interact with systems engineers for the [*if contractor,* government *or if government,* contractors]? If so, how are their roles different from yours?
- Q: What can the government do to help you at organization be better systems engineers?
- Q: When did you first learn about SE as a discipline?
- Q: How do you think young systems engineers today are different from young systems engineers 20 years ago?

Experience Questions (all)
N.B.: For questions depending on the role, use only the relevant questions.

- Q: What are the top 3 things you have to do in order to be effective in your current role? How did you learn these things?
    - If general trends or gradual experiences, move to next question. If specific ("point") experiences: If you had been exposed to these things earlier in your career, would that have helped? Would you have been able to learn from them earlier?
- Q: Are there key experiences that stand out in your path to becoming a systems engineer? (i.e. 'aha' moments)
- Q: What was the greatest challenge you've had in your career and how did you deal with it?

Junior/Mid-Level Questions

- Q: What role(s) do you want to have in 3/5/10 years?
- Q: With those role(s) in mind, what experiences do you need to do to achieve them?
- Think about what you want/need to do in the next 12 months? 5 years? 10 years?
- Q: Are there things other than experience you need to achieve these roles? (e.g. training, education, mentoring, certification, etc.)
- Q: Why do you believe these are the right things for you to do? What do you believe you will gain from them?
- Q: Do you believe that these are things you can do within your organization?
- Q: What were your expectations when you decided to pursue SE? Have your experiences met your expectations so far?

Mid-Level/Senior Questions

- Q: How soon do you think the junior systems engineers you work with will need to be ready to take roles like yours? What will make it easier or more difficult for them to fulfill your role?
- Q: What advice would you give to a young SE who is looking to be in your position someday? (N.B. It sometimes helps to ask the Mentoring questions first, and personalize this question, i.e. "Thinking about the people you currently mentor, what are the types of advice that you give most frequently.")
- Q: What were your initial expectations when you were exposed to SE? Have your experiences matched those expectations?
- Q: Thinking about your expectations when you started your career, is this where you thought you would end up?

Mentoring

- Q: What role has mentoring played in your development as a systems engineer? Have your experiences been formal or informal? If both, what are the differences in effectiveness between the approaches?
- Q: Do you currently mentor anyone or have a mentor? How were these relationships established? How is it going?

<u>Wrap Up</u>

- Q: Do you have any final comments or closing thoughts?
- Q: Are you willing to be contacted about participation in the future?

APPENDIX B – UPDATED INTERVIEW QUESTIONS

Getting to know you

- What brought you to systems engineering?
- Define your current role.
- Do you consider yourself a junior, mid-level, or senior systems engineer? Why?
- What are the top three (3) things you have to know or do in order to be effective in your current role?
- When you started your career, did you think that you would become a systems engineer?
- What were your expectations when you first learned about systems engineering? Has this matched what you've experienced?

What are the characteristics of systems engineers?

- Establish definition of systems engineer and definition of systems engineering workforce to be used in the rest of the interview (*from Helix, organizational, individual definitions*)
- Based on the read ahead, how does this definition of a systems engineer match what you see in practice?
- What are typical systems engineering activities performed in your organization? How are they related to other engineering and management activities?
- How common is it for people to perform systems engineering activities who are not classified as systems engineers and vice-versa?

How effective are systems engineers and why?

- Establish definition of the interviewee's effectiveness and effectiveness of systems engineering workforce to be used in the rest of the interview (from Helix, organizational, individual definitions)
- What are the most important forces that increase your effectiveness as a systems engineer? Why?
- What are the most important forces that inhibit your effectiveness as a systems engineer? Why?
- How do you assess your own effectiveness as a systems engineer?

What are employers doing to improve their effectiveness?

- What personal initiatives have you been taking to improve your own effectiveness?
- Which organizational initiatives in the last 5 years have been helping improve your effectiveness?
- Are these initiatives adequate? What more should be done?