Helix – Phases 1 and 2

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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?

Note that Helix is not studying "systems engineering" *per se*. Helix is focused instead on the people who perform systems engineering. The distinction is important and permeates how the research is conducted.

In its first year, Helix obtained information from seven organizations within the US Department of Defense (DoD) and the US defense industrial base (DIB). That information came from a combination of institutional reports (policies, demographics, career paths, etc.) and 90-minute interviews with 112 individuals, including systems engineers and those who work with systems engineers.

To date, the Helix team offers the following insights on the three research questions above:

1. **Question 1 – What are the Characteristics of Systems Engineers?**

Among the most important findings from the initial interviews is clarity about the mix of personal characteristics and technical competencies that are most important in a strong systems engineer.

Strong characteristics in leadership, communications, big picture thinking, personal networking, organization, being comfortable with uncertainty, understanding details, balancing conflicting information, and knowing the right questions to ask are common characteristics of the best systems engineers. Several of these characteristics are in tension – e.g., big picture thinking and understanding details. A good systems engineer can balance these conflicting characteristics.

The most important technical competencies include a solid understanding of least one discipline such as mechanical or electrical engineering, the ability to apply that understanding in depth within a domain such as telecommunications, and the ability to understand other engineering disciplines to the point of being able to ask insightful questions. Besides helping a systems engineer make the right technical decisions, these competencies increase the system engineer's credibility as a technical leader.

Three systems engineering-specific competencies stand out: being able to apply the overall systems engineering process, being able to work with stakeholders to develop clear, testable requirements, and understanding how all the system pieces fit together.

Typically there is a transition from an engineer being a "specialty engineer" to becoming a "systems engineer", and this can happen at any point in the career path. In this transition, it is important for the individual to focus on breadth rather than depth. Some disciplinary experts fail to make this transition well, which can make them ineffective as systems engineers.

2. **Question 2 – How effective are systems engineers and why?**

Understanding the effectiveness of systems engineers is complicated. Generally, interviewees had difficulty articulating what it means for them to be effective beyond staying within cost, schedule, and required performance parameters. Many said they were effective if they were able to follow organizational processes and procedures. Others said being effective means identifying issues and anticipating risks. Most interviewees built on their views regarding important characteristics and competencies; e.g., many said they were effective if they were able to pull together the right people on their team and have them work in harmony – a direct consequence of their leadership, communications, and personal networking characteristics. Many who were interviewed emphasized being able to predict and articulate the long-range impacts of actions. The significant time lag between a systems engineer's decision and others being able to see the results of that decision can hinder the ability of others to understand and appreciate the important role systems engineers play.

Interviewees articulated several important benefits they offer, including: translating highly technical information from subject matter experts (SMEs) into common language that other stakeholders can understand; eliciting the right requirements from the customer; balancing traditional project management cost and schedule concerns with technical requirements; seeing relationships between engineering disciplines and asking the right questions to balance these disciplines; and managing changes in requirements; and understanding future implications of current decisions.

Interviewees were asked what most improves their effectiveness. The two most common responses were strong mentoring and diverse experiences. Conversely, the most commonly cited inhibitors to effectiveness were confusion within the organization as to what systems engineering is and who the systems engineers are, the long time lag between when systems engineers make decisions and when the effects of those decisions are apparent, a failure of non-systems engineers to understand and appreciate the value that systems engineers bring, and compressed schedules.

3. **Question 3 – What are employers doing to improve their systems engineers' effectiveness?**

Although the Helix team has gained some insight into initiatives being conducted to improve systems engineers, it is premature to report these findings here. First findings on employer initiatives will be described in the next report.

In 2014, the Helix team will continue to analyze data collected to date and enrich that data with more interviews, institutional data, and perhaps other types of data sources as well. The next report will be published in Spring 2014. Additionally, Helix will hold one or two workshops in 2014 to explore and refine its findings with experts across the community; a primary goal of these workshops will be facilitating organizational understanding of the findings, helping organizations understand where these insights may provide keys to improving their own workforce initiatives, and helping organizations tailor their workforce initiatives based on these insights.

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 ever 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 removing 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 (generalist) systems engineers. It is unknown if these actions are producing the expected 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; 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 from both organizations.

Helix is a multi-year longitudinal research project, which proposes to gather data from many DoD and DIB organizations through a combination of techniques, including interviews with hundreds of systems engineers. Helix may reach beyond DoD and the DIB to gather data from other types of organizations as well.

This technical report is the first published by Helix, presenting early findings based on interviews conducted with over 100 systems engineers from seven organizations in 2013. The remainder of the report is organized as follows:

- Section 2 defines the research questions that Helix is trying to answer
- Section 3 explains the research methodology deployed
- Section 4 identifies the various data sources and explains how the data is collected and handled
- Section 5 discussed the methods used for analyzing the data
- Section 6 elaborates on the interviewee demographics and the early findings obtained from analyzing data collected in 2013
- Section 7 summarizes the findings and how they relate to the research questions
- Section 8 presents planned future work.

This technical report is the first of several that will detail an increasingly rich set of findings based on an ever-growing set of data.

2. RESEARCH QUESTIONS

In order to deepen the understanding of the systems engineering workforce, Helix is focusing on three main research questions:

1. *What are the **characteristics** of systems engineers?*

   There is no uniform way to identify people who are systems engineers. Some have the formal title "systems engineer," recognized as such by an organization's personnel system. Some individuals perform traditional systems engineering activities, but have another title, such as "systems analyst" or "project engineer". Some perform a mix of systems engineering and other activities. The Helix Project is seeking to understand the current ways DoD and DIB organizations (and perhaps other organizations) use to identify individuals who perform systems engineering activities. For example, if an individual spends 20% of his or her time performing systems engineering activities, is that person a systems engineer? What if he or she spends 51% on systems engineering activities? How do the characteristics of systems engineers vary with the mission of the organization, e.g. in acquisition organizations versus development organizations? The Helix team hopes to address these and other nuances as the research continues.

2. *How **effective** are systems engineers and why?*

   One clear way to address the challenges that the systems engineering workforce faces is to make existing and future systems engineers more effective. This naturally leads to questioning how to measure effectiveness and which forces, such as competencies, attrition, education, culture, environment, expectations, and experiences, have the greatest impact on the effectiveness of systems engineers. Helix is trying to answer those questions.

   Helix has posited generic definitions of individual and workforce effectiveness, which will evolve as it collects organizational perspectives:

   o An individual systems engineer is effective when the outcomes for which he or she is individually responsible are achieved as a result of the systems engineering activities he or she performs.

   o An organization's systems engineering workforce is effective when the outcomes for which it is collectively responsible are achieved as a result of the systems engineering activities it performs.

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

   Helix is trying to understand how organizations manage their systems engineering workforce as a whole. For example, are there organization-level policies governing the career advancement of systems engineers separate from policies for other engineers? Are there organizational initiatives to help young systems engineers get needed education, training, mentoring, and experience through rotational assignments? How well are those initiatives working? Are there competency models for systems engineers that guide personnel selection and job assignments? Helix is attempting to probe these areas across dozens of US defense-related organizations in both government and industry, looking for patterns of best practice and lesser practice.

3. RESEARCH METHODOLOGY

3.1 MIXED METHODS AND GROUNDED THEORY

The nature of data to be collected and the analysis to be performed for Helix require both quantitative and qualitative research methods; this is typically known as mixed methods research. (Creswell 2011)

Qualitative research aims to create or discover what things are made of, and what is created or discovered are called constructs. Qualitative research is useful for obtaining insight into situations and problems on which one has little knowledge *a priori*. This method is commonly used for providing in-depth descriptions of procedures, beliefs and knowledge, including the opinions of respondents about particular issues. Detailed data is gathered through open-ended questions that, among other things, provide direct quotations. The interviewer is an integral part of the investigation.

On the other hand, quantitative research begins once the constructs are in hand. It attempts to gather data by objective methods to provide information about relations, comparisons, and predictions and attempts to remove the investigator from the investigation. In the context of the Helix project, some quantitative research can be performed based on initial data collection; e.g., demographic information on systems engineers collected from resumes or from organizational data sources. Some quantitative research can only be performed after constructs are created utilizing qualitative research; e.g., understanding the strength of important characteristics and competencies of effective systems engineers within a certain population.

Since the Helix project did not presuppose a specific theory of systems engineers (important characteristics, competencies, relationships, etc.), a grounded theory approach was adopted. Grounded theory was developed in the social sciences as a method for developing theory that is grounded in data that is systematically gathered and analyzed. (Goulding 2002) Rather than beginning with a hypothesis, the first step is data collection. From the collected data, key points are marked with a series of codes, which are extracted from the text and numeric information. The codes are grouped into similar concepts. From these concepts constructs (categories) are formed, which are the building blocks of a theory. This approach is unusual in engineering research, where a researcher traditionally begins with a theoretical framework that he or she applies to the phenomenon to be studied. While each of the Helix team members has knowledge and experience in systems engineering, use of grounded theory for Helix is important to the project because it helps to remove the team's biases and allows for more open investigation and the discovery of "surprising" information. The team was concerned that an overly-structured approach would have a higher potential for missed insights.

3.2 OVERALL RESEARCH PROCESS

An overall process was defined for conducting Helix research following the grounded theory approach, as illustrated in Figure 1 below.

The process is intended to be iterative. The frequency and coverage of the individual loops is still evolving. Steps A and B are repeated for every organization. Step C is performed after collecting data from several organizations – currently, part of the data collected has been analyzed to produce preliminary findings. Additional analysis is being conducted to improve previous findings and to identify new ones. Steps D and E produce periodic public and private reports. This is the first public report. Private organizational reports will be prepared once there are sufficient participating organizations to

protect the identity of individual organizations. Step F is being conducted incrementally every time Steps B and C are executed.
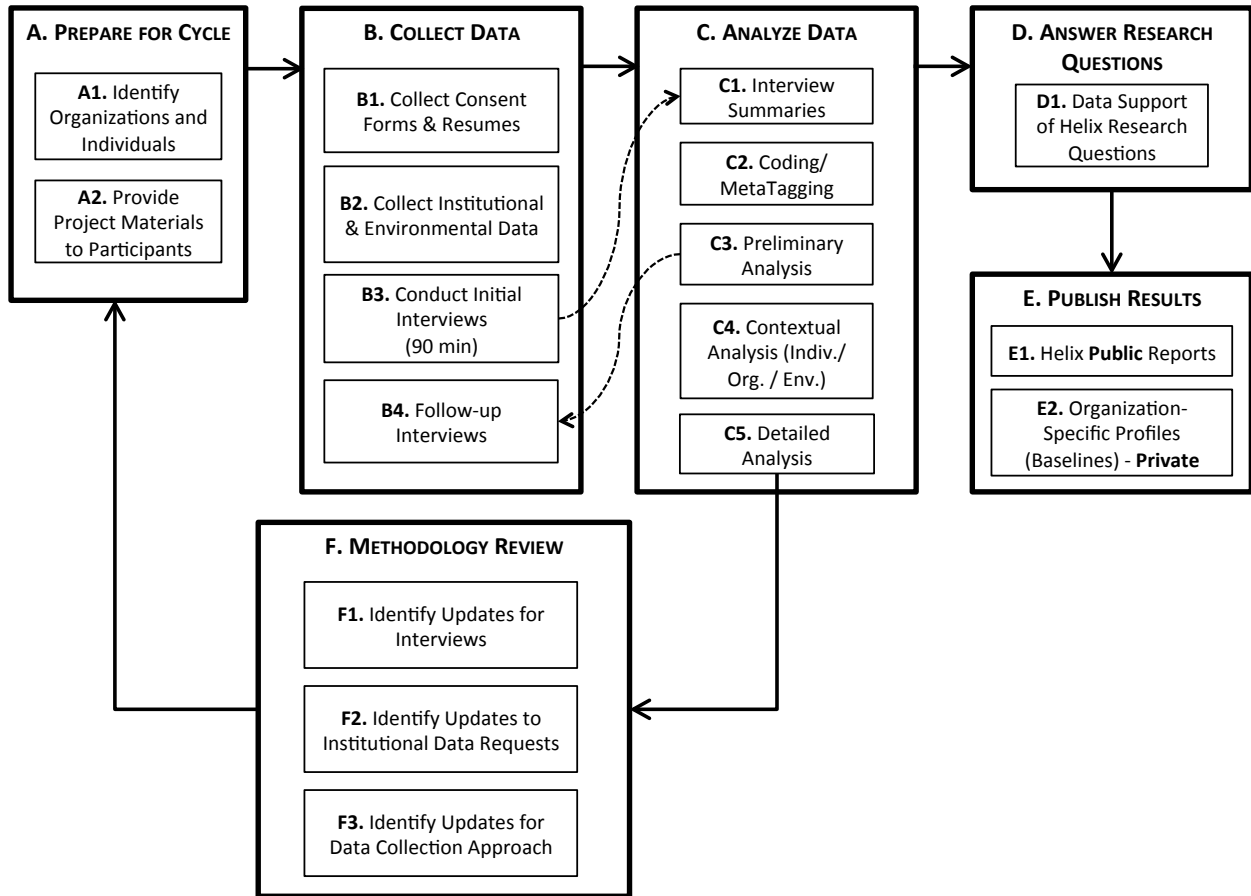

Figure 1. Helix Research Process

4. DATA SOURCES, COLLECTION, AND HANDLING

Helix has been collecting two primary forms of data from each organization: written institutional data, such as organizational policies about systems engineers, and interview data from face-to-face meetings with systems engineers and those who work with systems engineers.

4.1 ORGANIZATIONAL DATA

Organizational data has been obtained from various artifacts that each participating organization shares with Helix, typically under a non-disclosure agreement (NDA). Organizational representatives send the Helix team internal documents relevant to the performance of systems engineering activities and the management, development, retention, etc., of systems engineers. The Helix team then analyzes the artifacts, coordinates with organizational representatives to clarify any issues regarding the contents of those documents, and produces an organizational summary that is studied in advance of the face-to-face interviews and informs some of the interview questions. The Helix team requests the following types of data from each organization:

1. The charter or primary purpose of the organization;
2. The primary business of the organization, including revenue, primary customer, organization chart, and types of products and services delivered;
3. The total number of employees in the organization in each year since 2009, divided into engineers and non-engineers, including the number of people hired and departed;
4. The total number of systems engineers in the organization in each year since 2009 including the number of people hired and departed, along with an explanation of how the organization defines "systems engineer";
5. A characterization of the population of systems engineers with respect to highest college degree, number of years of professional experience, number of years of experience as a systems engineer, age, gender, title or rank (such as systems engineer, senior systems engineer, chief systems engineer, etc. using whatever titles or ranks that are part of the human resources system), and years to retirement eligibility;
6. The way in which the systems engineers are primarily organized; e.g., in a matrix structure or project structure;
7. Major previous or current organizational initiatives to improve the quality or quantity of systems engineers; and
8. Policies that are particularly relevant to systems engineers, including organizational competency model and career paths.

Over time, the requested information will undoubtedly evolve. No organization is expected to provide all the requested data. The data may not be readily available or the organization may not wish to share it with the Helix team. Nevertheless, with enough institutional data from a sufficient number of organizations, Helix will be able to address its research questions.

For very large organizations, the Helix team may interview several distinct segments of the organization. For example, for the US DoD, the DoD-wide approach may be the same, but there may be different policies or implementations within each of the Services. For large DIB organizations, it is possible that different branches may have different rules governing the SE workforce, hire people with different backgrounds, offer different forms of training, etc. Understanding the diversity within a single organization should provide further insight into the complexities and subtleties of the diverse roles systems engineers play throughout the community.

It must be noted that the Helix team has had unexpected difficulty in collecting this data from participating organizations. The major issue – which is further discussed in Sections 5 and 6 – seems to be that most organizations do not have a clear method for identifying or even defining systems engineers. This makes it very difficult to provide demographics on systems engineering population within an organization and even complicates the identification of relevant policies. The Helix team will continue to work with organizational points of contact (POCs) to obtain this information. However, it is currently and may possibly remain a gap in the information collected.

4.1.1 VISION FOR PARTICIPATION

To address these research questions, Helix has begun collecting data from organizations in both DoD and the DIB and, over time, hopes to collect data from dozens of additional organizations and perhaps a thousand individual systems engineers from those organizations. As of the writing of this report, Helix has collected data from seven organizations. Others have agreed to participate in the coming months, and several more are considering participation. In 2014 or 2015, the scope of Helix could be expanded beyond US DoD and DIB to include organizations from other business segments in the US or organizations from outside the US; however, such expansion has not yet been determined.

It is the vision of Helix to gather sufficient data that would truly represent the global systems engineering community, and the many variations within it in terms of:

- The nature of systems (engineering and otherwise),
- Geographical location,
- Government versus commercial organizations,
- The scale of systems or systems-of-systems, and
- Domains such as defense, finance, transportation, communications, and healthcare.

Current data focuses only on defense systems, but even within the defense application, participating organizations to date have worked across several domains and several have commercial business sectors. In 2014, the Helix team will attempt to incorporate a greater breadth of domains.

In addition to growing the diversity of organizations with respect to the above criteria, the Helix team wants to increase the representation within those criteria; e.g., collecting data from all of the largest DIB organizations who build and integrate major platforms (often referred to as the Tier 1 companies), many of their largest suppliers (the Tier 2 companies), and even some of the component suppliers (the Tier 3 companies). This is in addition to the many different organizations within the DoD itself; e.g., collecting data from all the Services and from organizations that work in different parts of the lifecycle, such as laboratories that work at the front-end of the lifecycle and depots that work at the tail end of the lifecycle. By building a sample that includes multiple examples for each of these criteria, the Helix team believes it will eventually be able to produce generalizable results.

4.1.2 VALUE TO PARTICIPATING ORGANIZATIONS

Helix research findings will be published in reports, papers, and presentations, providing important insights to the broad systems engineering community. However, the most immediate beneficiaries will be the individual participating organizations, which will:

1. Deepen their understanding of their systems engineering workforce over time,
2. Identify gaps and where to focus investments to improve the systems engineering workforce,
3. Benchmark their systems engineering workforce,
4. Deepen their understanding of what makes the workforce effective, and

5. Receive recommendations on how to improve the effectiveness of their systems engineers.

Helix has received feedback that just by participating in the project, some participating organizations have begun to reassess their approaches to managing and growing their systems engineering workforce.

4.2 INTERVIEW DATA

Interviews are conducted with a diverse cross section of individuals in each organization. Helix seeks people who:

- Are knowledgeable about the characteristics of systems engineers across the organization,
- Perform systems engineering on programs including both senior and junior personnel,
- Supervise systems engineers, and
- Use the products of systems engineers.

Interview questions are related to the three main research questions, and are only meant to initiate and guide discussions on various topics of interest to Helix. The interviews are conversations facilitated by the interviewer rather than a means to collect responses to a pre-determined set of questions. Examples of the Helix interview questions can be found in Appendix A.

4.3 PROTOCOLS AND APPROVALS

Due to the nature of the data to be handled in Helix, various approvals had to be obtained and agreements signed to ensure proper handling of data and protection of identities of individuals and organizations:

1. **Approval from Institutional Review Board (IRB).** Stevens Institute of Technology has an IRB to review all research that involves human subjects. All members of the research team had to complete training on Social & Behavioral Research that included ethical principles, human subjects, privacy, confidentiality, and other topics. The IRB reviewed the research methodology, data collection instruments, data handling protocols, and all relevant information before approving the Helix team to conduct research.

2. **Approval from DoD.** The project sponsors also required a review of the research methodology by a DoD agency to confirm that Helix satisfies all applicable DoD requirements.

3. **NDAs with participating organizations.** These are executed with participating organizations as per mutually agreed terms. Data is then shared with the research team; participants are assured of privacy and confidentiality of their identities and the information they provide.

4. **Consent Form from participating individuals.** All those who are interviewed sign a consent form that explains their rights and confirms that their participation is voluntary.

4.4 DATA SECURITY

The nature and quantity of the data to be collected warranted sophisticated measures for data security to be established before any data could be collected. It was expected that almost all data would be handled in electronic format, though they may be printed as hard copies for use by researchers or for archival purposes. For physical data, it was mandated that all data be under lock-and-key at all times except when being used actively, in which case it is under the direct supervision and control of Helix personnel. For electronic data, appropriate security solutions were identified for the following scenarios:

1. **Data exchange over email.** Data would typically be received from individuals and organizations via email; and the geographically dispersed nature of the research team meant that data would be frequently exchanged over email. Files sent between members of the Helix team were encrypted when transmitted using a commercial software tool.

2. **Data storage on researcher's machines.** To ensure secure handling of active data on the researcher's computer, a software package called TrueCrypt was chosen. TrueCrypt creates a secure volume in the local hard drive, which may then be mounted when needed. The entire file system within the volume is encrypted, and on-the-fly encryption ensures automatic encryption just before saving a file and automatic decryption just after it is loaded without any user intervention.

3. **Data storage on Stevens' servers.** Sakai Gateway is a secure private space provided by Stevens Institute of Technology to its researchers. All sensitive files stored on Sakai are encrypted.

5. DATA ANALYSIS

5.1 ASSUMPTIONS

Several fundamental assumptions underlie the Helix study and these influence the research methods, data analysis, and interpretation of the findings. Though some may seem obvious, it is important to state these assumptions, the risks if these assumptions prove false, and how the Helix team is mitigating these risks. Current assumptions include:

- **Validity of Responses.** There is an assumption that interviewees provide valid responses; that is, that the individual making the statements believes them to be factually correct or is sharing his or her true views on a subject. (Anderson 2010)

  The Helix team works to ensure valid responses in several ways. First, the team interfaces with a single point of contact (POC) in each organization; each POC is briefed on Helix, including the need for open and honest responses and the fact that any organizational influence on the participants (e.g. "if they ask you about this, here is what the organization believes . . . ") will damage the validity of the study. To date, all POCs have understood and agreed with this.

  All participants attend an informational session in which the Helix team discusses the need for open honest answers. The team confirms in the information sessions and again before each interview that neither the Helix team nor the organization has provided any incentives for participating or given instructions on how to respond. All participants are also assured throughout the process that their identities will not be revealed and that the team will only report anonymous results. The belief is that assurance of anonymity will help participants feel more comfortable answering honestly.

  The team believes that these measures are appropriate and sufficient, but recognizes that it is impossible to know with certainty whether participants are being completely honest. However, the team has seen a diversity of information and opinions within organizations, which indicates that it is unlikely that organizations are influencing the process. Finally, the team has an internal discussion after each interview as to the apparent openness of the participants based on observing body language, eye contact, etc. To date, the team does not have any reason to doubt the participants have answered in a way that reflects their personal views.

- **Participant Credibility.** There is an assumption that individuals who participate in Helix are effective and high performing and, therefore, may provide better insights into the systems engineering workforce than weaker systems engineers. The team specifically requests that POCs identify some of the best systems engineers in the organization for potential participation in the study. If this assumption is incorrect, it may mean that some depth or insights will be missed.

- **Validity of Organizational Representatives.** Each POC is asked to identify some individuals who can speak for the organization as a whole. The belief is that these individuals really do provide insight into the organization, as they understand the policies, processes, and tools and are also familiar with many of the larger-level workforce issues. However, most POC's have not clearly identified their "organizational" interviewees. Therefore, the Helix team looks to an organization's most senior systems engineers (herein called chief systems engineers, whatever their actual organizational title) to have a broad knowledge of the way systems engineering is

performed within the organization and a pulse on the SE workforce as a whole and considers them to be good systems engineers. The team considers these chief systems engineers to be organizational representatives and highly values their responses.

The team further assumes that these organizational representatives will not simply provide their personal opinions, but will provide a higher-order voice for the organization. Their responses are treated in this manner – as providing more insight at the organization level and providing valid perspectives on the population as a whole. If this assumption is not correct, the risk is that the population-level findings will be unduly influenced by the responses of these individuals. The team believes that the perspectives of other individuals who are asked to speak for themselves helps to balance this and to mitigate the risk. For example, the team has observed on several occasions that organizational representatives were well aware of improvement initiatives and state that the workforce is generally aware of these initiatives; the individual respondents, however, state that they are less aware of these. The individual contributors then balance these types of findings. This also becomes a point of interest for the individual organizations.

- **Objectivity of Helix Research Team.** The Helix team is taking every effort to remain objective, neutral, and unbiased in the entire research process. The interview questions are framed and posed to participants in a manner that should not imply any prejudice or would lead them in any particular direction. During the interview, participants are encouraged to share their opinions without being judged on what they are saying to be right or wrong. To date, there have been no concerns raised by the participants or their organizations on the manner in which the interviews have been collected or how the participants have been treated.

The Helix team believes these mitigation approaches are currently adequate and will remain vigilant to revise them as circumstances warrant.

5.2 ANALYSIS METHODS

Data is being analyzed using both qualitative and quantitative research methods. Quantitative analysis is possible for some of the data, such as demographic information, including the distribution of ages and number of systems engineers in an organization, which will be aggregated to different community segments, such as large versus small defense contractors.

Some of the more interesting analyses will be qualitative and will center around the most important activities systems engineers perform, what the most important characteristics of systems engineers are, and what makes systems engineers more or less effective.

A modified grounded theory approach is being followed at this stage of the research for qualitative analysis. A pre-determined set of interview questions is being used by the interviewer as a guide, but the interviews follow interesting lines of discussion triggered by comments from the interviewees. As a result, the interviews conducted so far have been based on some expectation on responses (hence not fully based on grounded theory), and the interviews explore the actual responses more deeply (hence not fully structured). The direction of the interviews are also informed by the resumes of those being interviewed as well as the institutional data collected from their organizations.

Data analysis begins with the creation of an interview summary. If an organization permits audio recording, transcripts are created that are the basis for summaries. Currently, the research team is using a qualitative analysis software package called Dedoose. The interview summaries are uploaded to Dedoose and are coded. There are multiple levels of coding:

- Direct responses to questions posed to the interviewees;
- Information that was not in direct response to any interview question;
- Patterns across interviewees within a particular organization; and
- Patterns across organizations.

In addition to coding of free text, characteristics of individual interviewees and organizations are also tabulated and cross-linked with the codes to provide deeper insights.

The identity of all interviewees is kept confidential and reports only include anonymous, aggregated data. The names of participating organizations are only revealed with their permission and in a manner that will not correlate them with research findings.

5.3 ANALYSIS CHALLENGES

Analysis to date has been based upon the interviews because institutional data has been surprisingly difficult to collect. The team initially believed that institutional data would be the primary component of the first report and would help set the context for preliminary findings from interview data. Most organizations do not have a clear method for identifying or even defining systems engineers. This makes it very difficult to provide demographics on the systems engineering population within an organization and even complicates the identification of relevant policies.

The Helix team had planned to provide analysis of interview information in the context of different types of organizational settings. Because this information is lacking in the current analysis, the findings can not be contextualized in this manner. The team will continue to work with POCs to build an understanding of the organizaitonal setting and fold this into the analyses going forward.

This is further complicated by the fact that only seven organizaitons have been visited to date. The small number makes it impossible to provide organizational classification while protecting the privacy of participating organizations. As the pool of participating organizations grows, the team will be able to provide more details by organization size, domain, technology focus, etc.

6. Early Findings

Enough data has been collected to report early findings, which fall into two categories: 1) interviewee demographics and 2) findings from interviews. The interviewee demographics describe information about the sample of individuals who have participated in Helix. The findings from interview data include characteristics and competencies of effective systems engineers; career paths for senior systems engineers; greatest contributions of systems engineers; factors that positively and negatively impact the effectiveness of sytems engineers; and potential risks to the systems engineering workforce.

These findings are based on the data that has been collected. Therefore, they may not be generalizable to the entire systems engineering population within the DoD and DIB. As Helix continues to visit more organizations and conduct more interviews, it is expected that a more representative sample will be developed such that findings may become generalizable. Further, in this report, no organizational-level findings are being reported since only a limited number of organizations in DoD and DIB have been visited to date and due to the difficulties in gaining access to organizational data, as discussed in Sections 4 and 5 above.

This report presents findings in an anonymous aggregated manner so that no observation may be traced back to an individual or to an organization. In light of this, there is data from the interviews that has not yet been analyzed and not included in this report. Future reports from Helix will update the current findings as well as offer new findings at the individual and organizational levels.

6.1 Interviewee Demographics

This section discusses the demographics of the sample of individuals interviewed to date for the Helix project. It represents 110 systems engineers from seven organizations. There were two additional interviewees who worked with systems engineers; these interviews are included in interview findings, but not in the demographic information below.

6.1.1 Sample Population

During 2013, seven organizations were visited and 112 participants were interviewed as part of Helix. Figures 2 and 3 indicate the number of interview sessions conducted per organization, and the total number of interviewees in each organization.
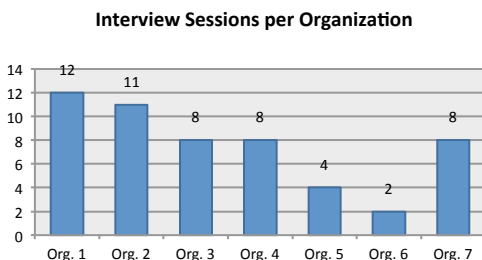

Figure 2. Interview Session per Organization
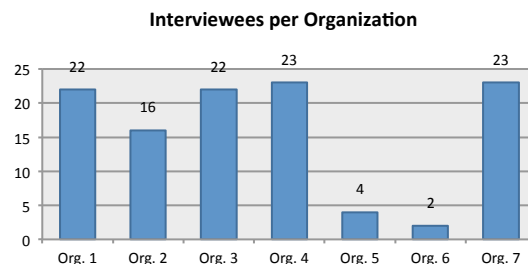
Figure 3. Interviewees per Organization

There were one to four interviewees in each interview session, as illustrated in Figure 4. Initially, the

plan was to conduct only individual interviews but due to scheduling constraints, more than one interviewee was included in most interview sessions. During those interviews, it was observed that the dynamic between the participants enhanced their responses. So, it was very effective to schedule two or three interviewees per session. In some cases, four interviewees were scheduled in a session due to constraints, but that was not preferred because it made it difficult to give enough time to gather data from every participant and to discuss several topics.

Interviewees per Session

4 interviewees
4%

1 interviewee
32%

3 interviewees
36%
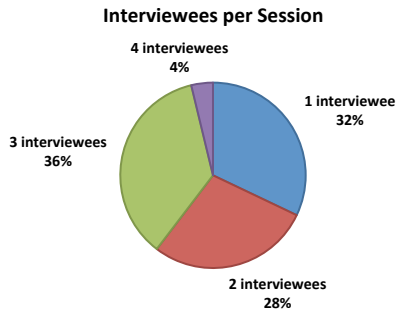
2 interviewees
28%

Figure 4. Interviewees per Session

Size of Interview Team per Session

4 interviewers
2%

2 Interviewers
43%
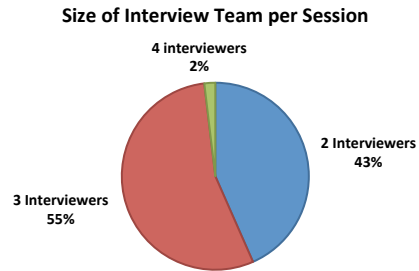
3 Interviewers
55%

Figure 5. Size of Interview Team per Session

Figure 5 illustrates the size of the interview team for the interview sessions conducted so far. Initially, the size of the interview team was three, to include one lead interviewer and two other researchers to take notes and ask additional questions. As the interview process matured over time, it was most effective to limit the size of the interview team to two, and this is the preferred size of the interview team going forward. A few interview sessions had four members on the interview team, only for the benefit of new incoming researchers to observe the interview process.

Since the interviews were conducted as conversations, and the data being collected from the interviews were highly unstructured and massive in size, it was highly preferred to record audio from the interviews and to use the transcripts from those interviews for further analysis. But this was first an organizational decision, and then the choice of the individual participant. As illustrated in Figure 6, while many interviews were recorded, 40% of the interviews could not be recorded largely due to organizational decisions.

Audio Recording

NO
40%

YES
60%
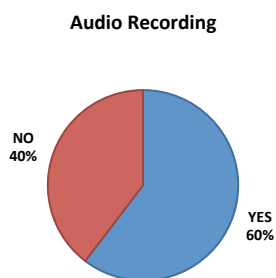
Figure 6. Audio Recording

Interview Mode

Telecon
4%
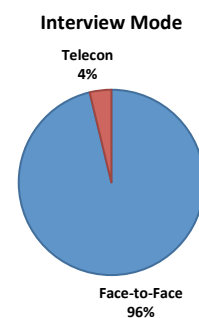
Face-to-Face
96%

Figure 7. Interview Mode

The intent of Helix was to conduct face-to-face interviews, in the expectation that this would provide the best environment for the interviewees to participate in the semi-structured interview sessions and for the interview team to respond to physical cues and to direct the interview in a comfortable engaging

manner. As illustrated in Figure 7, a few interviews were conducted over the telephone due to the locations of the interviewees and the number of interview sessions scheduled at that location. As best as the interview team could sense, most interviewees did exhibit confidence in the interview team and provided honest, sincere, and elaborate responses. However, there were some interviewees who by nature spoke less and it was difficult to extract much useful data from them. Helix will continue to use face-to-face interviews as the primary mode of data collection from individuals.

As noted earlier, Helix interviewed 112 participants but 2 of them were HR personnel, and not systems engineers. In the future, Helix will interview more such non-systems engineers: those who recruit, work with, or manage systems engineers who themselves are not systems engineers. The demographic information presented in the rest of this section is based on data from the 110 systems engineers only. An 'unknown' column is included in figures as appripriate, to account for interviewees about whom the requried data is not available. All findings reported in subsequent sections are also based on data from these 110 interviewees only.

The participants in the Helix interviews were predominantly male, as illustrated in Figure 8. The participants were always chosen by the respective organizations and not by the Helix team which stated some expectations on the diversity of participants. Figure 9 illustrates the distribution of the participants by age. It must be noted that age was not explicitly requested by Helix or provided by participants, but an indicative age was calculated based on the graduation year of their bachelor degrees. Hence, the exact ages may be off by a year or two, but the ranges are expected to be largely true.
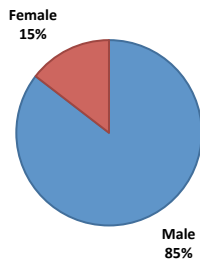
Figure 8. Interview Sample by Gender

Figure 9. Interviewee Distribution by Age

There is insufficient data to consider these distributions on gender and age to represent the entire population of systems engineers in the organizations or across DoD or DIB. This only represents the sample that participated in the Helix interviews.

Among the participants, more than 50% of the participants had a master's degree as their highest degree, as illustrated in Figure 10. But it is also important to note that about 30% of the participants did not pursue any formal education beyond a bachelor's degree. About 5% of them had a doctorate degree.

Highest Degree

Unknown
12%

Doctorate
6%

Bachelor's
29%

Master's
53%
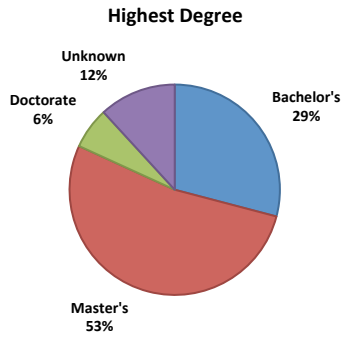
Figure 10. Highest Degree Attained for Sample Population

The majors of the bachelors degrees indicate a spread among engineering degrees, the highest in electrical engineering and related majors followed by mechanical engineering, as illustrated in Figure 11. This may be a reflection on the nature of systems being engineered by the organizations they work for and hence cannot be assumed to be true across DoD or DIB. It must be noted that some participants have non-engineering bachelor's degrees as well.
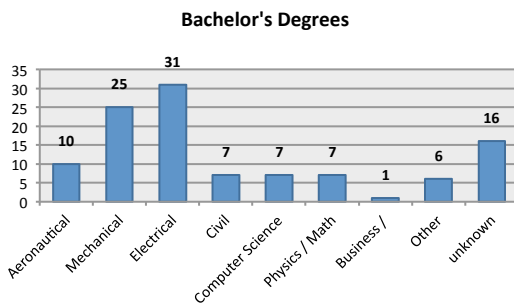
Bachelor's Degrees

Figure 11. Bachelor's Degrees
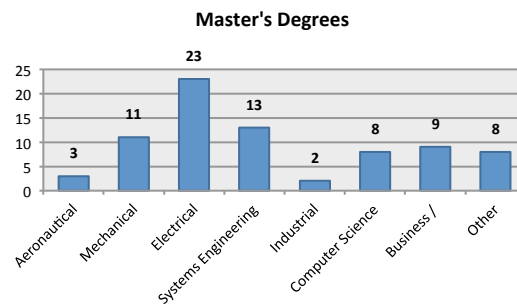
Master's Degrees

Figure 12. Master's Degrees

Figure 12 illustrates the majors for master's degrees. It must be noted that not every participant had a master's degree, and some participants had two master's degrees. Most master's degrees were in electrical engineering and related majors. Thirteen participants possessed a masters degree in systems engineering. Among those interviewed, seven of them held a PhD degree, and their thesis specializations were diverse:

- Aeronautical Engineering
- Anthropology
- Atmospheric, Oceanic and Space Sciences
- Electrical Engineering
- Geotechnical Engineering
- Mechanical Engineering

The interviewee demographics presented in this section illustrate the sample from which data has been collected through interviews. The findings presented in the subsequent sections are representative of this sample only, and may not be generalized beyond this to represent the larger population of systems engineers.

6.1.2 A First Look at Senior Systems Engineers

In view of the systems engineering workforce-related challenges to which Helix comes as a response, it was of interest to find out more about the senior systems engineers who are close to attaining retirement eligibility. The challenge is that while it was often difficult to identify a "systems engineer" in an organization (see further discussion in Section 6.2.5 below), it was even more difficult to identify a "senior systems engineer".

As a preliminary step to understanding the more senior population, 20 systems engineers have been identified from the current interviewee population based on a combination of their job title, years of experience, and nature of responsibilities. For this report, the Helix team has examined their education and high-level work experiences.

Figure 13 illustrates the education timeline of the 20 senior systems engineers. For each of them, the type of degree they obtained and the year in which they obtained it are indicated.
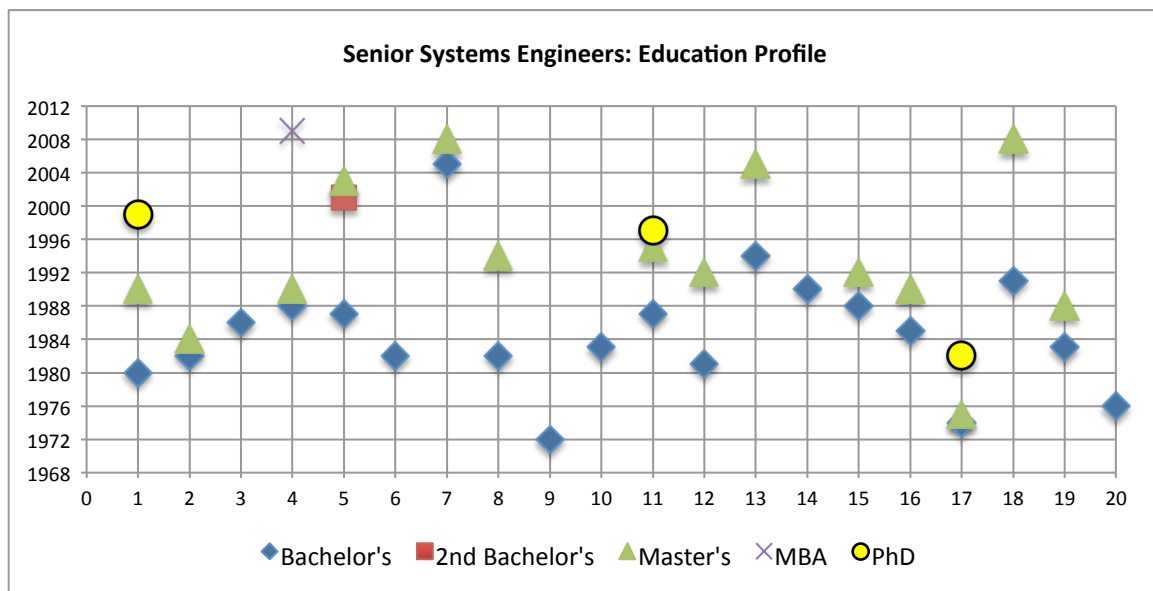
Figure 13. Education Profile of 20 Senior Systems Engineers

A number of observations can be made from Figure 13, illustrating the variety in this data:

- Three of the senior systems engineers interviewed have PhDs, but as indicated in Section 6.1.1, none of these degrees are in systems engineering.

- Six of them have only a bachelor's degree as their formal education.

- Seven have obtained their master's degrees almost immediately following their bachelor's degrees, while the other individuals with master's degrees have gathered years of work experience before getting a master's degree.

- Between them, these 20 senior systems engineers have earned 39 degrees. The most common areas of study were electrical engineering (16 degrees[1]) and mechanical engineering (8 degrees); other areas of study included computer science/software engineering and

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[1] Note: Some of these degrees were slightly different fields, like "electrical, electronics, and communication".

aeronautical engineering (both 3 degrees). The other areas of study were often specific to the domain of application or a hard science (e.g. physics). A few degrees were non-technical (e.g. MBA, music).

In terms of experiences of these senior systems engineers, analysis is ongoing due to the wide variety of experiences across this subsample. The Helix team is hoping to identify patterns with respect to the number of years of "systems engineering" experience vs. number of years of "specialty engineering" experience; the number of years experience in the current organization vs. number of years spent in other organizations including military service; the breadth of exposure to different types of systems and different phases of the systems engineering life cycle; and the sizes of their respective current teams (as peers or subordinates). Unfortunately, no patterns have emerged to date. However, the team believes that as the sample size grows, patterns may emerge. The team will also follow up with interviewees and expects to collect additional information about these experience profiles during follow up.

6.2   INITIAL FINDINGS FROM INTERVIEWS

There were several insights gained from the interviews conducted to date. For this report, the team has focused on the patterns of responses to capture points that are consistent across the sample. These have been grouped into the following six categories, and discussed in more detail in the following sub-sections:

1. The most important traits and competencies of effective systems engineers,
2. The greatest contributions of systems engineers,
3. What makes systems engineers most effective,
4. What makes systems engineers least effective, and
5. Potential risks to the systems engineering workforce.

It should be noted that there are other findings available from the data already collected which could not be included in this report because of available time or because they are integrally related to a specific domain and, therefore, would be tied to specific organizations. These additional findings will be included in future reports along with new findings that emerge as the size of the sample population grows and as more data is collected and analyzed.

6.2.1   THE MOST IMPORTANT CHARACTERISTICS AND TECHNICAL COMPETENCIES OF EFFECTIVE SYSTEMS ENGINEERS

The first research question that Helix is exploring is to understand the characteristics of systems engineers. This would be critical for various workforce development initiatives and help organizations decide the right mix of training/education methods to recruit and improve their workforce, to produce effective systems engineers. This will also help individuals recognize and address their strengths and weaknesses to become effective systems engineers.

While drawing out these characteristics from participants from interviews, in most cases, it was non-technical characteristics or "soft skills" that were provided. This led to further discussions on the importance of technical competencies for systems engineers, and the reasons they were considered important or not.

6.2.1.1   Characteristics

Interviewees were asked to identify and provide further insight into the most important characteristics of effective systems engineers. To help draw out their responses, they were encouraged to think about the best systems engineers they knew or worked for. Based on the responses received, five broad

themes have been identified and are elaborated below. Individually, many of these characteristics may be required of any technical leader or decision maker. However, the combination of these and some subtle nuances in the nature of these characteristics and why they are needed in a systems engineer, are insightful. Also, these characteristics are not mutually exclusive but rather support and complement each other. These themes discussed below are expected to mature with further data collection and analysis and are expected to support the building a theory of systems engineers.

6.2.1.1.1 Paradoxical Mindset

Looking at the all the characteristics that the participants listed, it was observed that many characteristics were actually contradictory to each other. Upon further discussion with the participants and deeper analysis, it was clear that effective systems engineers do possess seemingly opposite characteristics simultaneously and not just as a "balance" between the two extremes. In elaborating this mindset, an interviewee said "systems engineering is not for everyone" and that requires a "unique combination of left brain – right brain working together." Various such contradictory characteristics are identified below; in some cases both were identified by the same interviewee and by different interviewees in some others.

- **Big Picture Thinking *and* Attention to Detail.** Also referred to as "holistic thinking" or "systems thinking", "big picture thinking" was commonly identified as a very important and essential characteristic of systems engineers. An interviewee said, "the difference between a systems engineer and a design engineer is that a design engineer doesn't have to see the big picture." "Big Picture Thinking" relates to looking across dimensions of space and time with respect to the system of interest and its lifecycle. At the same time, a systems engineer is also required to pay attention to the detail. An interviewee elaborated "there are some people who can see through a microscope and others who are more visionary. A good systems engineer has some elements of both".

- **Strategic *and* Tactical.** Systems engineers need to be strategic, focused on the end result of "vision" for the system, but also need to handle the tactical day-to-day activities and decisions required to reach that vision. They must also be able to appreciate "how what is done today is going to affect things downstream".

- **Analytic *and* Synthetic.** A "big picture thinking" mindset can be associated with the ability to be synthetic and to be able to bring together and integrate different pieces of a puzzle together. But a systems engineer also needs to be analytic and be able to break down a big picture into smaller pieces.

- **Courageous *and* Humble.** Systems engineers need to be courageous as a leader and decision maker, but they also need to be humble are recognize the fact that there others who are experts in individual areas of specialization. They are confident in their abilities with a "lack of pride" and "don't feel the need to be defensive". They are also willing to accept their mistakes.

- **Methodical *and* Creative.** Systems engineers need to be disciplined, organized, diligent, and methodical in their approach. They need to stay focused on the end-result and the path towards that. However, they also need to be creative in thinking through the problems at hand and arriving at solutions.

6.2.1.1.2 Effective Communication

A large part of being a systems engineer is to be an effective communicator, in many different ways as elaborated below. Since systems engineers typically have a broader role in an organization than those with a niche, social skills in general and communication skills in particular, are very important.

- **Modes of Communication.** Systems engineers need to communicate in a variety of modes and types. They need to communicate orally (presentations, discussion, etc.) and in writing (documents, notes, reports, etc.). They must be good speakers and also be good listeners.

- **Audience.** Systems engineers also need to communicate with different people ranging from technical experts in the "solution domain" and various stakeholders in the "problem domain". A systems engineer serves as a bridge between these two domains. They need to communicate with individuals as well as teams. As elaborated by an interviewee, "you have to look high, you have to look low; and depending on your audience you have to adjust your communication."

- **Content.** The content of their communication could be social, managerial, or technical.

- **Purpose.** A systems engineer communicates for a number of reasons, most commonly: understanding needs, negotiation, information brokering, technical arbitration, driving consensus.

6.2.1.1.3 Flexible Comfort Zone

Every individual typically operates within a "comfort zone", and so does a systems engineer, However, an effective systems engineer is comfortable to go outside that "comfort zone" where required. An interviewee elaborated "experts have the fear of going outside of their circle or comfort zone that keeps them in that role [of an expert]".

- **Open Minded.** An effective systems engineer is open to different views, perspectives, and opinions from others. They tend to be unbiased and have small egos. Systems engineers may have to re-look at a decision that was taken many years ago because that was right at the time of decision-making may no longer be so, due to changes in technology or other reasons.

- **Rational Risk Taking.** Systems engineers are required to take rational risks while dealing with situations, for the sake of the larger system. Staying within one's comfort zone for fear of the unknown may not help in engineering the optimal system that meets the needs of the customer.

- **Multidisciplinary.** Unlike a disciplinary expert, a systems engineer needs to be multidisciplinary. He or she needs to understand unfamiliar disciplines for the sake of the system.

- **Enjoys Challenges.** A systems engineer does not shy away from challenges but rather embraces them as opportunities.

6.2.1.1.4 Smart Leadership

An interviewee said, "Systems engineers gravitate towards leadership because of the larger picture". Hence, irrespective of where they are in an organizational hierarchy, they tend play a leadership role because they interact with many individuals and teams, and are focused on the overall system. It was also said " a good systems engineer is one where everyone else is doing well, even if the system engineer is struggling".

- **Quick Learning and Abstraction.** Systems engineers tend to be quick learners, and have the "intellectual horsepower" to grasp how various things integrate together. They also have the ability to abstract what is said and capture the important and critical bits of information.

- **Knowing when to stop.** An effective systems engineer knows "what is good and good enough". They know when to stop doing a trade and move on without spending time and effort to arrive at the "absolutely optimal answer." They are also "willing not to dive into the detail". In dealing with disciplinary experts in the team, they also know when to stop being a leader, to offer the space and respect for those experts.

- **Focused on 'Vision' for System.** An effective systems engineer stays focused on the vision or end-result for the system. This focus helps the systems engineer in decision-making, resolving conflict, and in reducing ambiguity.

- **Ability to Connect the Dots.** A systems engineer has the ability to "connect the dots" from individual perspectives or contributions to form the big picture. This perspective also helps systems engineers spot pitfalls, identify problems, or recognize opportunities that are not seen by others.

- **Patience.** Though in a leadership role where decisions need to be taken, often quickly and effectively in response program pressures, systems engineers need to be patient and not jump to any conclusions. They demonstrate structured decision making, which requires patience and discipline.

6.2.1.1.5 Self Starter

Systems engineers possess a lot of energy and drive within themselves, without relying on external factors to initiate any action or response.

- **Curiosity.** Systems engineers tend to be curious and have a "somewhat wandering mind". They are not content with where they are and what they are doing. This is in contrast to many who just say, "this is my job". Systems engineers tend to ask the "why" question more often, without hesitating to wonder if it is a "stupid" question. One interviewee said, "I've made a career being the stupidest person in the room."

- **Passionate and Motivated.** Systems engineers tend to be passionate about their jobs and the systems they are working on. They possess enough motivation within them to drive themselves and others in the team.

- **Eager to Learn.** Systems engineers are always eager to learn new things and to educate themselves. In most cases, they are willing to go in search of the information that is not readily available. They also recognize that things are constantly changing (technology, needs, products, processes, etc.) and one needs to stay abreast of these.

6.2.1.2   Technical Competencies

The question of required competencies for systems engineers has been a subject of inquiry within the community for the last several years. Recently, the International Council on Systems Engineering (INCOSE) adopted the *Systems Engineering Competencies Framework*, which outlines required competencies in terms of systems thinking, holistic lifecycle view, and systems engineering management

(INCOSE 2010). However, there is still a debate about the level of general or specialty engineering competency required to perform systems engineering activities.

The *Graduate Reference Curriculum for Systems Engineering (GRCSE)* states that systems engineering masters students should have an undergraduate degree in engineering, the natural sciences, mathematics, or computer science; at least two years of practical experience in some aspect of SE; and the ability to effectively communicate technical information (Pyster and Olwell (eds.) 2012). These requirements indicate a view that there is some level of applied engineering understanding required for systems engineers to be effective. However, what depth of engineering competency – e.g. in electrical, mechanical, civil engineering, etc. – that is required is heavily debated. Some individuals believe – and in fact some organizations' selection processes indicate a belief – that systems engineers are the 'best of the best' from other engineering disciplines. (Pyster and Olwell (eds.) 2013; Adcock et al. 2012; Ferris et al. 2011)

During Helix interviews, when participants were asked about the need for and importance of "technical competencies", they referred to two types of competencies:

- **Engineering Competencies.** The current focus of Helix and the organizations that participated were all "engineering" systems. And so, when participants referred to "technical competencies", they were related to foundations of mathematics, physics, and basic engineering; and specializations in specific disciplines such as electrical engineering, mechanical engineering, or aeronautical engineering.

- **Systems Engineering Competencies.** While referring to "technical competencies", some interviewees related them to competencies of the discipline of systems engineering such as requirements, life-cycle processes, and architecting. One interviewee said, "not all systems engineers will be leaders; some systems engineers will stay technical and do architecture and requirements and they are good at it."

In elaborating the importance of effective systems engineers having to possess these technical competencies, responses varied from "not important" to "very important". It must be noted that these responses are based on the personal experiences of the individuals and their observations of "best" systems engineers they have encountered.

In analyzing the responses, the level of technical competence required for a systems engineer may be classified into two areas:

1. **At Present: More Breadth than Depth**

   Many responses referred to the need for technical competencies currently by systems engineers. Here is where a systems engineer is expected to have breadth of knowledge and understanding in a variety of disciplines related to the system. Interviewees explained the reasons why systems engineers must possess this breadth of technical competence:

   o To be familiar with technical language;
   o To appreciate the expertise and value of technical experts;
   o To understand the various disciplines related to the system;
   o To understand the needs of the customers and constraints of the disciplinary experts, and to evaluate technical feasibility;
   o To be able to integrate various disciplines;

o   For technical communication and to represent views of disciplinary experts to stakeholders; and

o   To be able to bridge the problem domain and solution domain.

2. **In the Past: Depth in One (or more) Disciplines**

While providing responses related to the importance of technical competencies for systems engineers, it was observed that interviewees were responding to technical competencies that systems engineers should have possessed in the past, but which they may not be actively using today. However, those technical competencies were needed, for the following reasons:

o   To appreciate the value of disciplinary analysis and design, and to understand the time, effort, and resources required;

o   To evaluate the validity of responses provided by disciplinary experts;

o   To appreciate aspects of sub-system level optimization and the need for system level optimization;

o   To understand the perspectives and constraints of disciplinary experts, and to be able to properly communicate them to managers and other non-technical personnel within the organization; and to the customers and other stakeholders;

o   To field questions from stakeholders in the absence of technical experts; and

o   For credibility and respect within the team and among stakeholders.

It is implicit in the above discussion that typically there is a transition from an engineer being a "specialty engineer" to becoming a "systems engineer", and this can happen at any point in the career path of the individual. In this transition, it is important for the individual to focus on breadth rather than depth, which may mean that the individual needs to be "willing not to dive into the detail", as discussed in the previous subsection on Characteristics (see discussion above). Responses indicated that many disciplinary experts sometimes fail to make this transition well, which can make them ineffective as systems engineers. One interviewee said, "I have seen people who have come from [a] very strong physics background, very strong electrical engineering background and made really horrible systems engineers." For those disciplinary experts who are unable to make this transition to becoming a systems engineer, "high technical skills may be an impediment" since "they want to sub-optimize and nail down all the requirements and nail down the system".

To be an effective systems engineer, there is a level of technical expertise that is currently required, but more important is to be able to transition from being a disciplinary expert to being a systems engineer possessing the required technical competencies at the required level and also possessing the characteristics and "soft skills" required to be one. One interviewee stated that the rule of thumb is "you have to know 10% depth in every discipline you work with".

6.2.2. THE GREATEST CONTRIBUTIONS OF SYSTEMS ENGINEERS

Systems engineering as a discipline will only prosper if its practitioners provide value-added to the projects and programs on which they work. Initially, the Helix team did not ask explicit questions on the benefits that each individual feels his or her SE activities provide. However, this theme appeared throughout the interviews. The most common interview responses regarding the benefits of systems engineers' work include:

•   Translating highly technical information from subject matter experts (SMEs) into common language that other stakeholders can understand;

- Balancing traditional project management concerns of cost and schedule with technical requirements;
- Asking the right questions;
- Seeing relationships between the disciplines;
- Staying "above the noise" and identifying pitfalls;
- Managing emergence in both the project and the system;
- Projecting into the future; and
- Getting the "true" requirements from the customer.

Managing emergence in both the project and in the system being developed is seen as an interesting response; however, it should be noted that it was not stated as frequently or by as diverse a set as the other items listed here.

Translating highly technical information into common language limits the miscommunications and often improves stakeholder satisfaction, as they can understand why certain desires may not be met or why certain project aspects may take longer than others.

Several interviewees reported that the specialty engineers they work with often feel so over-burdened by cost and schedule pressures that it is difficult for them to meet the bare minimum technical requirements. Systems engineers "protect their teams" by helping project or program managers understand the technical issues, and therefore support decisions about when cost and schedule changes are absolutely required to meet technical requirements. Conversely, systems engineers can also help determine when technical concerns are not required but are rather "polishing the apple" and can be traded in favor of cost and schedule.

Several interviewees indicated that this also allows them to address potential problems before they have a chance to impact the system as a whole; i.e. it's an effective tool for risk management that allows examination of the approach overall, not just the specifics of one component or discipline.

As one interviewee stated, this allows "everybody [to] get to the same conclusion that this is the correct path or the best path to follow because you drew it out into the open". In other words, systems engineers help to balance competing technical approaches by addressing system-wide implications of those approaches. Bringing this perspective to the team enables the technical specialists to see where "it might have been better actually if [they] had come up with a suboptimal solution for [their] little part because you'd arrive at a much better solution for the collective."

There is a clear relatinship between the contributions of systems engineers and the skills required to bring those contributions to fruition. In future reports, the team will explore the relationships between these elements as it works to build a theory of systems engineers.

6.2.3. WHAT MAKES SYSTEMS ENGINEERS MOST EFFECTIVE

The underlying intent of all workforce development initiatives is to create or mature an effective workforce. Therefore understanding what increases or decreases a systems engineer's ability to be effective is of great importance for anyone engaging in such workforce development activities. This section will explore what effectiveness means for a systems engineer and what enables effectiveness. Inhibitors of effectiveness can be found in the next section.

6.2.3.1 Effectiveness

In order to explain what best enables a systems engineer to be effective, it is first important to define effectiveness. The Helix project began with a generic definition of effectiveness, which was that "an

individual systems engineer is effective when the outcomes for which he or she is individually responsible are achieved as a result of the systems engineering activities he/she performs." This generic definition was presented to interviewees, who were asked to respond to and add to it. In general, interviewees agreed with this as a generic outline.

In more specific terms, interviewees indicated that a systems engineer is effective when he or she delivers a system that aligns with schedule, cost, and technical requirements, and satisfies the customer, "getting quality equipment out to the field". Metrics for evaluating the effectiveness of systems engineers are difficult for many reasons; specifically, interviewees believed that the time lag between SE decisions and the results of those decisions being seen made any quantitative assessment particularly difficult.

Though metrics for the effectiveness of systems engineers seem to be uncommon and imprecise, several qualitative indicators were discussed by the interviewees. For example, "you haven't had a major rework because of a requirement that was missed or an interface that was missed"; systems engineers have "… anticipate[d] where the issues might be …" and developed methods to mitigate or resolve issues quickly. One participant stated that, "an indirect method to measure effectiveness is to look at the number of programs the systems engineer has participated in, non-conformances, red programs, win rates." Finally, "in many ways a systems engineer is an orchestrator for everybody else to do their job. Whether or not you're writing requirements or you're conceiving what the whole system is, it's an orchestration of everyone. So [an effective] system engineer is one where everyone else is doing well. If the system engineer is struggling but everybody else is doing well, he's probably struggling the right way."

With this view of effectiveness in mind, each interviewee was asked to identify factors that make it easier for them to be effective. There was a wide variety of answers, some of which overlap with some of the characteristics of systems engineers discussed earlier. This report explores the factors of diversity of experiences and mentoring, as from the interviews conducted thus far it is evident that these are two of the most important aspects of enabling effective systems engineers. This section will also discuss the relationship between the organizational value of systems engineering and effectiveness.

6.2.3.2   Diverse Experiences

SE is a practical discipline; its benefits are conferred primarily through application. It is widely accepted that practical experiences are therefore a critical component of the development of systems engineers. There is much debate in the community about how much time is required to mature a systems engineer and what types of experiences are required. This report does not attempt to address all concerns with regards to experience; this will be a major focus for Helix going forward. However, a consistent theme from almost all interviewees was that diversity of experience is critical to the maturation of systems engineers.

Specifically, the majority of interviewees believe that systems engineers need to gain multiple types of experiences, which may include:

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

This diversity of experiences enables systems engineers to develop the characteristics and competencies that make them more effective, as discussed above. For example, seeing in practice the interaction between different disciplines, the results of decisions made in one phase of the life cycle manifested in another phase of the life cycle, and experiencing problems with interfaces all help a systems engineer to develop and refine big picture thinking.

This diversity of experiences also enables systems engineers to develop pattern recognition across domains that help them to identify risks or issues early ("give red flags") or identify "golden opportunities" that might have otherwise been missed. These abilities are supported by the development of the habit of asking "the why questions"; i.e. as systems engineers experience different approaches in different contexts, they have the opportunity to ask and learn why one approach may be better in one context than another. This in turn gives them the ability to use that context to examine approaches in new areas and probe when an approach does not seem to fit the context. From this, systems engineers build their "toolbox" of approaches, methods, and specific tools, which enable them to perform SE tasks more efficiently in future. Some interviewees have also stated that more diverse experiences correlate with having more open-minded approaches and therefore better enable SE.

Further benefits of diversity of experience discussed during the interviews included gaining the opportunities to experience failure and learn from it ("build scar tissue"). It is important to note this scar tissue can occur even without diverse experiences; however, gaining scar tissue across multiple areas is seen as a means to better enable the internalization of systems engineering principles. For example, some interviewees stated that individuals who had worked only on QRC-type projects did not understand the value of formal requirements generation. They needed the opportunity to fail (on a small scale) because of incorrect requirements on a more formal project in order to begin building the skills to be more discerning about the application of the systems engineering process in specific contexts. Some interviewees also stated that experience with different program mangers – some who are supportive of SE and others who want to jump immediately into design – provides more opportunities to experience rework, and therefore reinforce the SE approach.

Finally, there are orthogonal aspects of systems that are of particular importance. For example, in many defense systems, weight is a critical system attribute that impacts all components, overall system performance, and the ability of the system to fulfill the concept of operation. The critical attributes may differ depending on the domain, but it appears that for each organization there is at least one. Several interviewees stated that if they had understood the importance and impact of these system aspects earlier, it would have helped them create better designs with fewer errors. They also stated that the only way they understood this was to see the implications in practice; this is not something that they believed they could fully grasp from a training course. It may be beneficial for systems engineering organizations to identify these critical systems attributes for the relevant domain(s) and ensure that junior systems engineers gain experience and focus on these early in their careers.

Many organizations, including several of the organizations participating in Helix, have programs designed to enable systems engineers to build a portfolio of experiences early in their careers. In addition to having the benefits listed above, as a workforce development tool, interviewees indicated that this approach enables individuals to select which areas of systems engineering best align with their skill sets and interests. Several interviewees stated that by exposing junior systems engineers to the different options, they were more likely to choose an area they would be interested in and less likely to leave the company or transfer to a non-technical track.

There is a caution about diversity of experiences, however: diversity must be balanced with depth. Several interviewees stated that they have observed a recent trend in younger systems engineers that is overly focused on breadth – and that these 'generalist' systems engineers struggle without the proper

engineering underpinnings. A few ways to deal with this include allowing systems engineers to gain experience throughout the entire life cycle on a single project. This allows breadth of experience in the life cycle, but depth in the domain. Another challenge with some rotational programs is that diverse experiences are gained through short assignments. In these instances, there is no opportunity to "break something" or to see the longer-term effects of one's efforts. A commonly cited approach that interviewees indicates works well is diversity early in ones career but with some stable aspect (e.g. project, domain, etc.), a deeper dive with less diversity mid-career, and diversity at a higher level later career with the deep technical experience to support higher-level positions.

The question of how long it takes to mature a systems engineer, the optimal balance between diversity of experiences and depth in a domain or specialty, and the best timing for these experiences are still debated, and the Helix team will continue to investigate these issues.

6.2.3.3   Mentoring

As discussed above, diverse experiences are critical for the development of systems engineers. Interviewees see mentoring as a strong accelerating function for growing the competencies[2] that are required to be an effective systems engineer. Mentoring, then, is a tool that enables systems engineers to get more value from their experiences.

Mentoring has had several meanings to the individuals interviewed thus far: career mentorship, which focuses on helping individuals understand how they can best grow as systems engineers; organizational mentorship, which focuses on helping an individual navigate within his/her current organizational environment; and technical mentorship, which focuses on helping an individual improve his/her technical performance in context. Technical mentorship often involves the mentor acting as SME and helping a less experienced person identify pitfalls and opportunities and is generally discussed similarly to an apprenticeship.

In most formal mentoring arrangements discussed, the mentor and mentee are paired up by the organization. This does not always work for two main reasons: "not every senior systems engineer is a good mentor" and a good match between the mentor and mentee cannot always be guaranteed. There is no defined way of becoming a good mentor. Interviewees were not able to identify any training that could be provided. However, there are indicators to identifying a good mentor that organizations can use to select mentors for a formal mentoring initiative, many of which include the traits discussed above such as big picture thinking, staying "above the noise", and the ability to communicate technical information. These skills allow a mentor to help his/her mentee see through to the true issues in their systems and determine appropriate solutions; ideally, these solutions will be applied and the mentee can then understand the outcomes in practice. This sort of apprenticeship was cited by many as crticial to the development of good systems engineers. The preponderance of interviewees stated that they participate in some form of mentoring, though most of them stated that the more successful mentoring experiences have been informal.

It is worth noting that the above are all forms of active mentorship – an interaction between individuals to enable growth. There were also many examples of passive mentorship mentioned – i.e. many interviewees stated that having strong systems engineers available as role models was also very important for their growth. Interviewees stated that this is facilitated when senior systems engineers are "doers", individuals who "roll up their sleeves" to provide direct technical value on a system.

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[2] The data for Helix shows that there are different types of competencies: general engineering competencies; specialty engineering competencies; systems engineering competencies; and non-technical competencies such as leadership, communication, etc.

The absence of mentoring may not be apparent in any direct, tangible manner. There may be other ways through which systems engineers may obtain the competencies fostered by a mentorship or apprenticeship-style arrangement. However, interviewees indicated that these alternative routes might be more laborious, time consuming, or less certain than mentoring. The Helix team will explore this question more deeply in future interviews.

6.2.3.4   Value of Systems Engineering

Though not surprising, several interviewees stated that when systems engineering is valued as a discipline, it creates an environment in which it is easier to apply systems engineering principles and processes. This can occur when a customer places particular value on systems engineering or when an organization places value on the discipline. Interviewees stated that when systems engineering is desired by the customer, it becomes very easy to implement the process, as most organizations participating in Helix are driven by a desire to "make the customer happy".

This desire for SE may be counterbalanced by budget and schedule considerations. (See discussions below.)

6.2.4. WHAT MAKES SYSTEMS ENGINEERS LEAST EFFECTIVE

The Helix team has observed that although the systems engineers interviewed believe that they make valuable contributions to their projects and programs, there are factors that seem to inhibit their ability to be as effective as they would like. Some of these factors are the inverse of the enabling factors discussed above; e.g. if a mentoring culture or having access to strong mentors is an enabler, then lack of mentorship opportunities may inhibit effectiveness. Likewise, several factors discussed have a correlation with a lack of the characteristics of effective systems engineers as discussed above; e.g. effective systems engineers are holistic thinkers, therefore systems engineers who have trouble thinking outside of specific disciplines will be less effective. While these types of statements are consistent with the data, this section focuses on interviewee's statements about inhibitors that are not a simple corollary to the enabling factors.

6.2.4.1   Ambiguous Definition of Systems Engineering

The majority of interviewees across several organizations stated that the organizational understanding of "systems engineering" is blurry. This may be for a variety of reasons. Some of the organizations interviewed to date do not have a formal definition of systems engineering; clearly if there is no standard definition, there will be inconsistent views on what systems engineering is and therefore what systems engineers do. Of the organizations that do have a formal definition, the definition was often not well known – even to the systems engineers. Another commonly-cited problem is dilution of the term – using the term "systems engineering" to cover too many activities, some of which have been labeled differently for years. Some interviewees observed that this was due to organizational recognition of the importance of SE, but the implementation has made it less understandable. One interviewee stated that the shift occurred while he was undergoing project management training and "suddenly everything that [he] thought was project management was systems engineering." This is true also for SE terminology: "… So when I say 'subsystems' they don't mean the subsystems I'm talking about. When they say system, they don't mean the system I'm talking about."

6.2.4.2   Unclear Use of 'Systems Engineer' Title

Confusion about the term "systems engineering" is further compounded by the fact that the title 'systems engineer' is used differently within each participating organization. In some organizations,

there may be a 'systems engineering division' or similar and all individuals within that organization are labeled 'systems engineers', even if they actually perform electrical engineering, or manage logistics, etc. Several interviewees stated that this makes it very hard to make a case for the value of SE because their peers do not understand what they will get when they add a "systems engineer" to the project. In organizations where the label of "systems engineer" is applied more intentionally, this is less of an issue, though interviewees from these organizations still indicate problems with the consistency of terminology.

6.2.4.3   Limited Value of Systems Engineering in Organizational Culture

As seen in the interview data, one of the primary activities of a systems engineer is often to explain and get peer buy-in on the value of SE. When there is no consistency in the use of this terminology, this task is more difficult and individuals must be won over on a case-by-case basis. This is particularly challenging when project managers do not understand the value or role of SE with regard to the sub-optimization of components for the good of the system; i.e., project managers may view systems engineers as unnecessarily limiting the effectiveness of specialty engineers if they do not understand the holistic perspective of SE. Systems engineers must ensure that both the project managers and specialty engineers understand the interplay between disciplines; again, this is more difficult when the cultural value for SE is weak. This tension is often also manifest in the schedule; if project managers don't understand the value of performing rigorous requirements development, for example, they often become frustrated with systems engineers for "holding up the process". As one interviewee stated, the "general perception [is] that SE is good to do – but when it comes time to fund it, it's often the first thing cut." Systems engineers, therefore, have to spend more time and energy trying to convince the organization of the value of SE than would their counterparts from classical engineering disciplines.

6.2.4.4   Systems Engineering Tools

Many individuals highlighted a lack of SE tools as making it more difficult for them to do their work. Some indicated that this is due to organizational inhibitors, so that the tools that exist are not available to them. As discussed above, this seems to be linked with the organizational value of SE. When tools are available, several interviewees stated that there is insufficient training or mentorship on the tools, which makes it difficult for them to be effectively used. Some interviewees stated that the tools available to them are simply not robust enough to support the true system-level analysis on very complex systems. Finally, there is a feeling that a lot of time and effort are required to convince project managers of why these tools should be used. No justification is required for tooling for other disciplines (e.g. "a designer doesn't have to convince the PM [program manager] that he needs access to CAD3 [software]."). It seems that it is simply not as ingrained in corporate cultures that SE tools are needed.

6.2.4.5   Visibility of Failures vs. Successes

A key challenge cited in championing the value of SE is that failures are extremely visible, while successes are often the opposite; i.e. there is little to draw attention to success. Instead, effective systems engineers' projects are marked by a lack of rework and successful fielding – i.e., what is traditionally expected. Some interviewees stated that systems engineers could take advantage of this by citing examples of where SE efforts failed and all of the associated effects. They could indicate where improved SE most likely would have led to a better outcome.

6.2.4.6   Valuing Process over Critical Thinking

Even in organizations that recognize or have begun to recognize the value of systems engineering, the actual implementation of SE may make it more difficult for systems engineers to perform efficiently. For

example, some systems engineers said parts of their organization value the SE process over critical thinking. When failures happen, the SE process is expanded to address that failure, creating a heavyweight and inflexible process.

Other interviewees stated that though at the organizational level there is a message of valuing systems engineering, it often becomes a "check the box" process – engineers begin focusing on producing specific deliverables within the process instead of using those deliverables as tools to improve the system. In fact, several interviewees stated that this mentality becomes pervasive over time, to the point that even if systems engineering deficiencies are identified in a review, a system may still pass the review, with no additional steps or rework required.

6.2.4.7   Younger Systems Engineers Fail to Recognize the Importance of Process

As an inverse of the previous discussion, several interviewees stated that many of the younger systems engineers have grown into the discipline using less rigorous processes. For example, the QRC approach, used heavily in the defense community in the last decade, was a necessary enabler to allow fielding of systems to the warfighter in an extremely expedited manner. This "quick reaction" has been enabled by a necessary reduction is the formality of the systems engineering process. As Operations Iraqi Freedom and Enduring Freedom draw to a close, the perceived need for the QRC approach is also decreasing. This means that the more formal approach of traditional systems acquisition may be implemented more strongly going forward. Several examples were cited of systems engineers who have had only QRC experience trying to transition to a project with a more rigorous SE process. These younger systems engineers have struggled, often expending more energy fighting against the process than working with it.

Several interviewees stated that it is important to tailor the systems engineering process so that it is appropriately rigorous for the type of system being designed. However, for the young systems engineers with little or no experience in more formal programs, the default position seems to be "less process is better". Specific examples were discussed when individuals who performed well in QRC approaches did very poorly in larger, more traditional programs. It was stated that this is more common when someone saw only successes with QRC programs. A few interviewees stated that individuals who had the opportunity to see where the less rigorous QRC process allowed a breakdown in system capability, integration, etc., tended to be more open to rigorous systems engineering approaches.

6.2.4.8.   Inadequate Knowledge Management

Several interviewees discussed the lack of and need for knowledge management activities. This was generally discussed in two contexts. First, general best practice of identifying lessons learned on programs – many interviewees stated that they spend a large amount of time capturing lessons learned upon completion of a project or program. However, when they need to access this information in future, it is almost impossible to find. Second, many interviewees stated that they are concerned about the loss of knowledge as more senior systems engineers leave the workforce (for more information, see subsection 6.2.6.1, below). Many of these people believed that rigorous knowledge management could help prevent or mitigate some of this loss. However, several organizations have no organized knowledge management approach and of the ones that do have a formal approach, several interviewees indicated that there is a breakdown in input, storage, and search capabilities, rendering these sometimes large-scale efforts almost useless.

6.2.5 PERCEIVED RISKS TO THE SYSTEMS ENGINEERING WORKFORCE

Nearly every interviewee was asked to identify his or her top one or two areas of concern with regard to the SE workforce over the next five years. There were many organization-specific concerns, but across organizations, several patterns emerged. The most commonly cited risks are:

- The high percentage of senior systems engineering personnel nearing retirement;
- The shifting environment; and
- The expectations of the junior systems engineering workforce.

Clearly, concern about retirement would be addressed if the more junior workforce was adequate to fill any gaps. However, there are also concerns about the expectations – and resulting retention – of the younger systems engineering workforce. All of this is occurring in the context of the shifting environment, which includes both operational, acquisition, and economical concerns.

Each of these issues is discussed in more detail below.

6.2.5.1 High Percentage of Senior Systems Engineers

As stated in the Introduction of this report, one area of interest to DoD is the age profile of the SPRDE (Systems Planning, Research, Development, and Engineering) workforce, specifically the implication of the high percentage of the workforce at or nearing retirement age. (Welby 2010, Welby 2011, Torelli 2012) This profile can be seen in Figure 13.
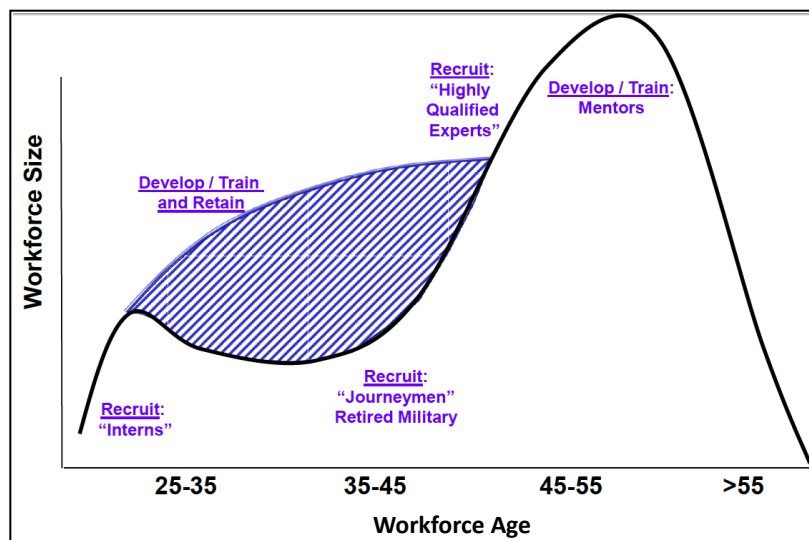
Figure 14. Age Profile of the DoD SE (SPRDE) workforce (Welby 2010)

The Helix team posed this issue to the interviewees, with mixed reactions. First, this "bathtub curve" profile does not exist in all organizations. In addition, some individuals stated that they felt they had sufficient mechanisms in place to deal with this and it was not a concern or that the junior systems engineering workforce is extremely promising and will "rise to the challenge". The current sample of seven organizations is too small to draw conclusions about the wider systems engineering workforce. However, it is evidence that this may not be a consistent problem.

Second, in organizations that do have a higher percentage of at- or near-retirement systems engineers, there were very mixed reactions to the issue. One consistent issue, however, was the common concern

for losing "specialty" systems engineers – those with deep expertise in a specialty discipline or a specific domain or application – over "generalist" systems engineers.

In organizations where this is a major concern, there are several different approaches for dealing with this issue. For example, several individuals cited a formal "succession plan" in which individuals who may soon retire are identified along with potential successors. The methods of grooming potential new senior systems engineers almost all include mentoring or apprenticeship; some include specific types of training. The level at which this is handled is not consistent; in some organizations it is handled by HR, in others by managers, and in others it is owned by the systems engineers themselves. Some organizations also state that they bring back senior systems engineers as consultants for a period of time to help ease their transitions.

Several individuals stated that it was not only *not* a problem, but instead an opportunity. As one interviewee put it: "Good riddance!" Though flippant, this response highlights a pattern seen in responses from several mid-level systems engineers. There are perceived to be a very limited number of senior systems engineer positions, so individuals who are mid-career in systems engineering must wait until a senior position is open before they can advance their careers. This has led to frustration, so the possibility of increased retirement rates may provide opportunities for people looking to advance.

6.2.5.2   Shifting Environment

In the current environment – a shift from a war-time posture to a peace-time posture – interviewees expect to see an increase in measures like sequestration along with the continued draw-down of deployment activities and a decreased need for QRC developments. Smaller and fewer programs are anticipated, leaving less opportunity for diversity of experiences and making it more difficult for seasoned senior systems engineers to develop. Further pressures to do programs more cheaply is anticipated to have a negative effect on systems engineers, for though it should mean a focus on the value add of systems engineering, interviewees believe that instead the up-front costs will become harder to justify.

The retirement issue may also be complicated by early retirement, which is anticipated in the new financial and defense climate. Several interviewees stated that the shifting environment may make SE as a discipline less desirable. Specifically, there is concern that young systems engineers may not believe that SE will provide sufficient career opportunities. Several interviewees stated that they have already seen a trend that many of the younger systems engineers choose to go into management roles and quickly move out of technical roles. This compounds the issue of being able to back-fill retirees.

6.2.5.3   Expectations of Young Systems Engineers

Several interviewees expressed concern over the expectation of the younger generation of systems engineers. Specifically, several interviewees cited grooming programs for young systems engineers that seem to send the message that these high-potential individuals will quickly become leaders in systems engineering. There is often an expectation that in a short period of time (5-10 years is often cited) that these younger systems engineers will be in senior systems engineering positions. As stated above, the population is in many places top-heavy, with few open senior positions. This leads to disillusionment, causing many younger systems engineers to move between organizations looking for upward mobility. The changing environment, as discussed above, also impacts this view.

Several interviewees also cited examples of young individuals who did quickly obtain senior positions, but who were ultimately not prepared for the task. They cited lack of diversity of experiences as a primary factor that individuals often do not thrive in these positions. Again, these perceived failures

might be encouraging the younger generation of systems engineers to leave the technical roles and pursue management roles.

7. ALIGNMENT OF FINDINGS WITH HELIX RESEARCH QUESTIONS

The purpose of the Helix project, as discussed in Section 2, is to answer three research questions. While all insights into the systems engineering workforce are relevant, it is critical to understand how the information gleaned from analysis to date helps to answer the research questions. It is important to note that while there are some very useful insights in these areas, there is considerably more work to be done before the questions can be fully answered.

7.1 QUESTION 1 – WHAT ARE THE CHARACTERISTICS OF SYSTEMS ENGINEERS?

Ideally, to answer this question the Helix team will provide a landscape view of the systems engineering population and be able to draw conclusions about commonalities. However, as discussed above, it has been surprisingly difficult to identify systems engineers at the population level, so at the time of this report, the team must rely on information about the individuals who were interviewed.

The team does have early insights about the most important characteristics and competencies of systems engineers (as discussed in Section 6 above). Perhaps the most important take away here is that there is a mix of personal characteristics and technical competencies that seem to be important for creating a good systems engineer. Technical competencies include a basic understanding of engineering fundamentals, the ability to apply these fundamentals to some depth within a domain, and the ability to understand other engineering disciplines to the point of being able to ask insightful questions. These things all go to increasing the credibility of systems engineers as leaders, but are effectively considered baseline requirements. To that end, characteristics such as strong leadership, communications, big picture thinking, curiosity, attention to detail, humility, etc. – which are sometimes conflicting – seem to be common in systems engineers. Finally, there are some systems engineering-specific competencies that are important, which include facets such as understanding the systems engineering process, tracing between requirements and testing, and understanding how the components integrate into the complete system.

7.2 QUESTION 2 – HOW EFFECTIVE ARE SYSTEMS ENGINEERS AND WHY?

The question of effectiveness of systems engineers is, it turns out, not straightforward. It is a combination of following processes and procedures and helping to identify issues in real time – which can generally be assessed – and of predicting the long-range impacts of today's actions. This time lag complicates the understanding of effectiveness both for systems engineers themselves and for their counterparts in project or program management, other engineering disciplines, and organizational management.

Despite this, however, the team has been able to identify patterns in what benefits systems engineers believe they provide to their projects or programs. These include translating highly technical information from SMEs into common language that other stakeholders can understand; getting real requirements from the customer (versus wants, implementation constraints, etc.); providing a balance of project management concerns (cost/schedule) with technical requirements; seeing relationships between engineering disciplines and asking the right questions to balance these disciplines; managing emergence, i.e., managing the issues that arise under uncertainty; and projecting into the future. Reflexively, then, effective systems engineers are engineers who can do each of these things.

The team has also gained some additional insights into what conditions most improve systems engineers' effectiveness. Though many items were discussed, the two most common responses were that a strong mentoring relationship and a diverse experience base are very important for systems

engineers to become effective. Conversely, there were many common responses to what factors inhibit the effectiveness of systems engineers. For example, lack of clarity regarding the definition of systems engineering or who within an organization actually performs systems engineering tasks dilutes the organizational view of the value of systems engineers and systems engineering. When this is not understood, it becomes difficult to justify SE-related efforts when budgets and schedules are compressed, as is often seen in today's environment. Another often-cited detractor from valuing systems engineers is the time delay associated with systems engineering. Both the up front delay – i.e. time spent understanding the problem and not 'producing' – and the time lag between when decisions are made and when the results of those decisions are manifest were cited as complications in understanding the value of SE for people outside the discipline.

7.3   QUESTION 3 – WHAT ARE EMPLOYERS DOING TO IMPROVE THEIR SYSTEMS ENGINEERS' EFFECTIVENESS?

While the team does have some insight into initiatives being conducted to improve systems engineering, it is impossible for the team to draw any firm conclusions at this time. With only seven organizations providing data to date, the sample size is too small to have much validity and would be too revealing about the individual organizations participating in the Helix project. During 2014, with a large sample of organizations, the team will be able to report findings for Question 3.

However, as discussed above it can be noted that all participating organizations recognized the risks associated with retirement of the senior systems engineers, who represent a significant portion of the workforce in many places. Three common initiatives for mitigating this risk were: initiation of more purposeful mentoring organizations; succession planning with associated apprenticeship; and improvements to knowledge management.

8. FUTURE WORK

There are some specific content areas of interest to the team going forward. For example, the team will continue to work with participating organizations to gain more information on organizational initiatives, population statistics, etc. Also, the team to date has worked primarily with systems engineers or systems engineering managers; the team will focus on getting participation from more individuals outside of systems engineering – specialty engineers, program managers, etc. – to help validate some of the findings. This will be particularly helpful for findings such as systems engineers' perceived value added; it will give the external perspective and help to validate whether what systems engineers believe they contribute is the same as what other individuals value in systems engineers.

The team will also work on a deeper dive on some of the current findings. For example, there is data on the importance of a diverse set of experiences for systems engineer effectiveness, but the team will spend some focused time with interviewees exploring this in more depth. The same will be true for several of the other findings outlined in this report. Additionally, the team will focus effort on the collection of demographics and examine how the demographic information influences the interpretation of the findings.

The Helix team is building a theory of systems engineers and will continue to conduct interviews and collect and analyze other forms of data in order to refine and validate this theory. The team expects to release several public reports in 2014 on its findings. The first of these reports will outline the theory of systems engineers. Additionally, the Helix team plans to conduct workshops in 2014 where SMEs have an opportunity to review that theory and associated findings and help the team to validate and refine their conclusions.

The team is also examining the possibility of incorporating additional data sources for 2014, including information from professional societies and data from organizations outside the US defense community.

In addition to data from individuals and participating organizations, Helix expects to capture some environmental data that may have influenced the data collection. For example, lay-offs, mergers & acquisitions, freeze on hiring, constraints on education and training, changes in organization leadership, project successes or failures, support for participation in conferences and other professional events, and other such factors could significantly affect the responses of the interviewees. It is proposed to capture such environmental factors to provide a context to the data being collected.

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GLOSSARY

ACRONYMS & ABBREVIATIONS

Acronym/Abbreviation	Meaning
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
IR&D	Internal (or Independent) Research & Development
IRB	Internal Review Board
NDA	Non-Disclosure Agreement
NDIA-SED	National Defense Industrial Association – Systems Engineering Division
POC	Point of Contact
QRC	Quick Reaction Capability
SERC	Systems Engineering Research Center
SME	Subject Matter Expert
SPRDE	Systems Planning, Research, Development, and Engineering
UARC	University-Affiliated Research Center

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)*.

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 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 – SAMPLE INTERVIEW QUESTIONS

Some typical questions that have been posed to junior systems engineers, reflecting on their personal situations, are:
- What activities do you perform most frequently?
- What are the most important activities that you perform?
- Are you spending the right amount of time on the most important activities?
- What were your expectations when you first took this position? Does that align with what you do now?
- How well does your management understand and appreciate what you do?
- How common is it for people to perform systems engineering activities who are not classified as systems engineers and vice-versa?
- What are the most important personal traits that make you an effective systems engineer? Why?
- 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 could you become a more effective systems engineer?
- How is your performance as a systems engineer evaluated and rewarded? What metrics are used?
- What personal initiatives have you been taking to improve your own effectiveness?
- Which organizational initiatives in the last five years have been helping improve your effectiveness?

Similar questions are posed to more senior-level interviewees, and these individuals are sought to represent not just themselves but the organization as a whole. Some typical organizaton-related questions are:
- Is there a gap between the effectiveness of your systems engineering workforce and your organizational need?
- How is the performance of your systems engineering workforce evaluated and rewarded? What metrics are used? Are they uniform across the roles and levels of the systems engineering workforce?
- What are the primary risks to the systems engineering workforce in the next five years? How are these risks being addressed?
- Which organizational initiatives in the last five years have had the greatest impact on the forces that improve workforce effectiveness? How do you know this?
- How did your workforce respond to these initiatives?
- Are these initiatives adequate to close the gap between effectiveness and organizational need? What more should be done?