



## **WRT-1004: Helix**

Technical Report SERC-2020-TR-007

July 7, 2020

**Principal Investigator:** Dr. Nicole A.C. Hutchison, Stevens Institute of Technology

**Co-Principal Investigator:** Dr. Dinesh Verma, Stevens Institute of Technology

### **Research Team:**

**Stevens Institute of Technology:** Dr. Pamela Burke, Dr. Hoong Yan See Tao, Mr. Ralph Giffin, Dr. Zhongyuan Yu, Mr. Deep Makwana, Mr. Xinyu Chen, Ms. Yao Xiao

**Sponsor:** Office of the Under Secretary of Defense for Research and Engineering (OUSD(R&E))

Copyright © 2020 Stevens Institute of Technology, Systems Engineering Research Center

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

This material is based upon work supported, in whole or in part, by the US Department of Defense through the Office of the Assistant Secretary of Defense for Research and Engineering (ASD(R&E)) under Contract [HQ0034-19-D-0003, TO#0127].

Any views, opinions, findings and conclusions or recommendations expressed in this material are those of the author(s) and do not necessarily reflect the views of the US Department of Defense nor ASD(R&E).

No Warranty.

This Stevens Institute of Technology and Systems Engineering Research Center Material is furnished on an “as-is” basis. Stevens Institute of Technology makes no warranties of any kind, either expressed or implied, as to any matter including, but not limited to, warranty of fitness for purpose or merchantability, exclusivity, or results obtained from use of the material. Stevens Institute of Technology does not make any warranty of any kind with respect to freedom from patent, trademark, or copyright infringement.

This material has been approved for public release and unlimited distribution.

## TABLE OF CONTENTS

---

|                                                                                                                            |            |
|----------------------------------------------------------------------------------------------------------------------------|------------|
| <b>Table of Contents .....</b>                                                                                             | <b>iii</b> |
| <b>List of Figures .....</b>                                                                                               | <b>v</b>   |
| <b>List of Tables .....</b>                                                                                                | <b>vi</b>  |
| <b>Acknowledgements.....</b>                                                                                               | <b>1</b>   |
| <b>Executive Summary .....</b>                                                                                             | <b>2</b>   |
| <b>1 Introduction .....</b>                                                                                                | <b>4</b>   |
| 1.1 About This Document.....                                                                                               | 5          |
| <b>2 Background .....</b>                                                                                                  | <b>6</b>   |
| <b>3 Overall Helix Methodology .....</b>                                                                                   | <b>8</b>   |
| 3.1 Web-Based Survey.....                                                                                                  | 10         |
| 3.1.1 Selection of Survey Sample .....                                                                                     | 11         |
| 3.2 Individual Assessment Tool.....                                                                                        | 12         |
| 3.3 Organizational Assessment Tool .....                                                                                   | 15         |
| <b>4 Helix Findings.....</b>                                                                                               | <b>19</b>  |
| 4.1 Organization Attributes that Support Systems Engineering Workforce Effectiveness .....                                 | 19         |
| 4.2 Systems Engineering Effectiveness .....                                                                                | 19         |
| 4.2.1 Systems Engineering-Specific Survey Data within an Organization .....                                                | 20         |
| 4.3 Systems Engineering Governance, Methods, Processes, and Tools .....                                                    | 22         |
| 4.3.1 Findings on the Effectiveness of Systems Engineering Governance .....                                                | 24         |
| 4.3.2 Findings on the Effectiveness of Systems Engineering Processes .....                                                 | 26         |
| 4.3.3 Findings on the Effectiveness of Systems Engineering Tools .....                                                     | 29         |
| 4.3.4 Systems Engineering-Specific Data Analysis on Governance, Methods, Processes, and Tools Within an Organization ..... | 29         |
| 4.4 Culture .....                                                                                                          | 33         |
| 4.4.1 Culture Analyses within an Organization .....                                                                        | 33         |
| 4.4.2 Culture Analyses across Organizations .....                                                                          | 41         |
| 4.4.3 Cross-Cultural Insights from Research in the Netherlands, the United Kingdom, and the US .....                       | 42         |
| 4.5 Systems Engineering Value .....                                                                                        | 46         |
| 4.6 Systems Engineering Analyzer Dashboard.....                                                                            | 49         |
| 4.7 Atlas Update .....                                                                                                     | 56         |
| 4.8 Systems Engineering Capability .....                                                                                   | 59         |
| <b>5 Discussion .....</b>                                                                                                  | <b>62</b>  |
| 5.1 Caveats for Interpreting the Data .....                                                                                | 62         |
| 5.2 Insights About Conducting This Kind of Research .....                                                                  | 62         |
| 5.3 Insights from Related Sources and Scholars.....                                                                        | 64         |
| 5.3.1 Culture Change Efforts at the DoD .....                                                                              | 64         |
| 5.3.2 Taking a Systems View of Culture .....                                                                               | 69         |
| 5.3.3 The Nuances of Creating Psychological Safety .....                                                                   | 71         |
| 5.3.4 Perspectives on Increasing Organizational Agility .....                                                              | 75         |
| 5.4 Effectiveness Measures .....                                                                                           | 77         |

|                                                                        |            |
|------------------------------------------------------------------------|------------|
| <b>6 Conclusions.....</b>                                              | <b>79</b>  |
| <b>6.1 Research Questions .....</b>                                    | <b>79</b>  |
| <b>6.2 Summary of Key Findings.....</b>                                | <b>80</b>  |
| <b>7 Recommendations.....</b>                                          | <b>85</b>  |
| <b>References .....</b>                                                | <b>86</b>  |
| <b>Appendix A: List of Publications .....</b>                          | <b>91</b>  |
| <b>Appendix B: Glossary .....</b>                                      | <b>96</b>  |
| <b>Acronyms and Abbreviations .....</b>                                | <b>96</b>  |
| <b><i>Atlas</i> Definitions.....</b>                                   | <b>96</b>  |
| <b><i>Atlas</i> Classifications .....</b>                              | <b>98</b>  |
| <b>Appendix C: Competing Values Framework (CVF) .....</b>              | <b>101</b> |
| <b>Appendix D: Quality of Interaction Index (Qi Index).....</b>        | <b>103</b> |
| <b>Appendix E: Full Results of the Systems Engineers' Survey .....</b> | <b>105</b> |
| <b>Appendix F: Results of the Peers' Survey .....</b>                  | <b>113</b> |

## LIST OF FIGURES

---

|                                                                                                          |    |
|----------------------------------------------------------------------------------------------------------|----|
| Figure 1. Relationship between Helix and Products Developed in the Project .....                         | 6  |
| Figure 2. Overall Helix Data Collection.....                                                             | 9  |
| Figure 3. Demographics of Helix Interview Participants .....                                             | 9  |
| Figure 4. Demographics of Helix Survey Respondents .....                                                 | 10 |
| Figure 5. Survey Respondents.....                                                                        | 12 |
| Figure 6. Updated Self-Assessment Tool (User Dashboard) .....                                            | 13 |
| Figure 7. Proficiency Assessment Results .....                                                           | 14 |
| Figure 8. Career Path Assessment Results .....                                                           | 14 |
| Figure 9. Admin Dashboard .....                                                                          | 15 |
| Figure 10. Screenshot of the Organizational Assessment Questionnaire .....                               | 16 |
| Figure 11. Screenshot of User Interface to Participate in the Survey for a Specific Organization.....    | 17 |
| Figure 12. Screenshot of the Organization Owner's Data Analysis Dashboard .....                          | 18 |
| Figure 13. Organizational Systems Engineering Effectiveness .....                                        | 20 |
| Figure 14. Within-Organization Ratings 1.....                                                            | 21 |
| Figure 15. Within-Organization Ratings 2.....                                                            | 21 |
| Figure 16. Within-Organization Ratings 3.....                                                            | 21 |
| Figure 17. Competing Values Framework Analysis of Four High-Tech Industry Companies.....                 | 22 |
| Figure 18. Helix Survey Responses to the Statement.....                                                  | 23 |
| Figure 19. Helix Survey Responses to the Statement.....                                                  | 24 |
| Figure 20. All Survey Responses on the Effectiveness of the Current SE Processes...                      | 26 |
| Figure 21. All Survey Responses on the Availability of Tools to Do Systems Engineering Effectively.....  | 29 |
| Figure 22. Organization X Responses on the Statement .....                                               | 30 |
| Figure 23. Organization X Responses to the Statement .....                                               | 31 |
| Figure 24. Organization X Responses to the Statement .....                                               | 32 |
| Figure 25. Example from within an Organization with Multiple SE Divisions .....                          | 34 |
| Figure 26. Within-Organization Qi Index Analysis of Organizational Behaviors, Emotions, and States ..... | 34 |
| Figure 27. Within-Organization Competing Values Framework Data .....                                     | 36 |

|                                                                                                               |     |
|---------------------------------------------------------------------------------------------------------------|-----|
| Figure 28. Across-Organization View of Perceived Status of Systems Engineers (by Systems Engineers) .....     | 41  |
| Figure 29. Across-Organization View of Overall Systems Engineering Effectiveness (by Systems Engineers) ..... | 42  |
| Figure 30. SE Analyzer Dashboard Framework .....                                                              | 50  |
| Figure 31. SE Knowledge Repository Tab in the SE Analyzer Dashboard.....                                      | 51  |
| Figure 32. Industry Tab in the SE Analyzer Dashboard .....                                                    | 52  |
| Figure 33. Industry Tab in the SE Analyzer Dashboard (Continued).....                                         | 53  |
| Figure 34. Organizational Survey Data Analysis Tab in the SE Analyzer Dashboard ...                           | 54  |
| Figure 35. Example of Organizational Culture Survey Data Analysis Tab in the SE Analyzer Dashboard.....       | 54  |
| Figure 36. Opinion Tab in the SE Analyzer Dashboard .....                                                     | 55  |
| Figure 37. Generalized overview of Organizational Effectiveness .....                                         | 56  |
| Figure 38. <i>Atlas</i> .....                                                                                 | 57  |
| Figure 39. Career Path: A Dynamic View of <i>Atlas</i> .....                                                  | 59  |
| Figure 40. Importance of Not Confusing “Comfort” with Psychological Safety (Snow, 2020).....                  | 75  |
| Figure 41. Consistent Delivery of Systems Engineering Values.....                                             | 78  |
| Figure 42. Competing Values Framework adapted from Cameron and Quinn (2011)                                   | 101 |

## LIST OF TABLES

---

|                                                                                                                                         |     |
|-----------------------------------------------------------------------------------------------------------------------------------------|-----|
| Table 1. Culture Descriptions for Interview Data Sorted into Competing Values Framework Quadrants for Organization A.....               | 37  |
| Table 2. Culture Descriptions for Interview Data Sorted into Competing Values Framework Quadrants .....                                 | 38  |
| Table 3. Primary SE Values and the Ways Organizations Impact SE Effectiveness.....                                                      | 46  |
| Table 4. Representation of the Culture in Organization A .....                                                                          | 63  |
| Table 5. Representation of the Culture in Organization C .....                                                                          | 64  |
| Table 6. Organizational Impacts on Effectiveness .....                                                                                  | 81  |
| Table 7. Criteria for Distinguishing the Seniority of Systems Engineers.....                                                            | 98  |
| Table 8. Example of the OCAI current profile for dominant characteristics (Cameron and Quinn, 2011, pp. 30, used with permission) ..... | 102 |

## ACKNOWLEDGEMENTS

---

We have greatly enjoyed our eight-year journey on Helix. Since 2012, we have had the opportunity to work with hundreds of practitioners and dozens of organizations, share our findings with audiences around the world, and gain valuable feedback and support from the systems engineering community. There is no way we can possibly thank every individual who has participated adequately. Simply put, this research would not have happened without you.

We have had the opportunity to work with several individuals from our government sponsor, and we gratefully acknowledge Nicholas Torelli, Kristen Baldwin, Scott Lucero, Philomena Zimmerman, and Nadine Geier for their support, without which this research would not have been possible.

The team has been lucky enough to do this work as part of the Systems Engineering Research Center (SERC). The SERC brings together leading minds from the systems engineering community; through this, we have had the opportunity to gain valuable insights from many of our colleagues. In particular, we'd like to acknowledge Tom McDermott, Jon Wade, Bamini Ketheesan, Punam Patel, Todd Walker, Mimi Marcus, Maia Canlas, James Walsh, and Monica Brito. Our Director, Dinesh Verma, not only helped us make connections around the world, but also served as a member of the Helix team, and we gratefully acknowledge his contributions.

We have had the pleasure of having individuals support the Helix team outside of the US, and gratefully acknowledge Wouter Leibbrandt, Frans Beenker, Joris van den Aker, and Jacco Wessilius in the Netherlands, and Duncan Kemp and Sam Williams in the UK.

I would like to thank all members of the Helix research team, both past and present. In particular, I would like to acknowledge Art Pyster, whose leadership and dedication in the beginning of the project were critical and instrumental to its success and who still champions and supports Helix today. Past members of the Helix team also deserve recognition for their hard work and dedication: Deva Henry, Sergio Luna, Kahina Lasfer, Jose Ramirez-Marquez, Michael Pennock, Pete Dominick, Jon Wade, Carlo Lipizzi, Ricardo Pineda, Araceli Zavala, Shikha Soneji, Suchita Kothari, Bruno Salgado, Megan Clifford, Shipra Manchanda, Monis Kamil, and Matthew Partacz.

Finally, I am immensely grateful to the current Helix team. You have inspired me through your dedication, excellence, and tremendous work. Pam, Ralph, Dinesh, Yan, Annie, Deep, Neal, and Yao, I am humbled to have had the opportunity to work with you.



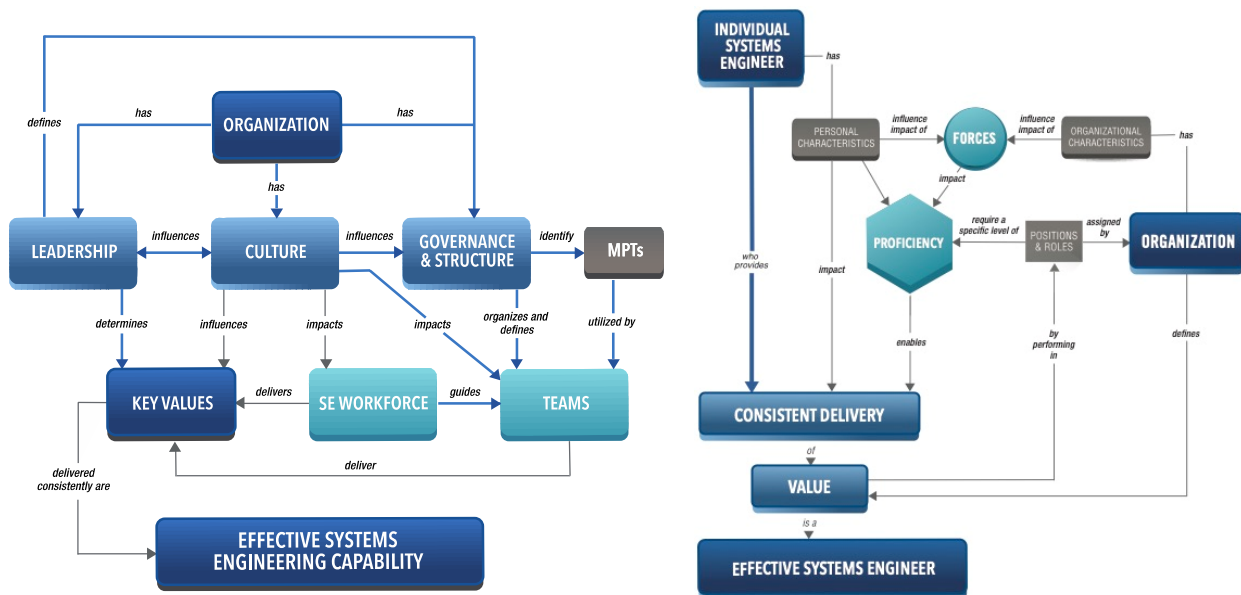
Nicole AC Hutchison  
Helix Principal Investigator

## EXECUTIVE SUMMARY

What does it mean for an individual or organization to be effective at systems engineering? This is the central question addressed by the Helix project since 2012. *Atlas* is intended to answer this question.

“Systems engineering” as a term is used heavily in the defense and aerospace industry, but the values that the discipline can provide are critical to many industries, though terms like design, systems architecture, or product engineering may be used in lieu of systems engineering. At its core, systems engineering is an approach that enables a holistic view on engineering and design of systems – products, services, enterprises, and missions – in context, and the diverse needs of different types of people who can benefit from these systems. It is a way to be both systematic and systemic. If this is of value for you or your organization, then the findings and recommendations in *Atlas* are worth reading and discussing.

Atlas has two lenses: that of an individual systems engineer and that of the organization that employs systems engineers:



Following is a recap and summary of findings from the analyses:

- Systems engineers and others are ready, willing, and able to think about and discuss how systems engineering is working in their organizations and what needs to be done to improve effectiveness. Ask them!
- There are likely to be perception differences among systems engineers, their managers, and other stakeholders. Increasing transparency of perceptions is an important step to collective improvement in conditions, expectations, and results.
- Organization culture variables that encourage free discussion, empowerment to make decisions, and respect for the systems engineering discipline have a positive effect on effectiveness.

- Structure and governance variables such as limiting silo behavior and having seats at the highest-level decision tables may increase effective communication and data-driven decisions.
- Having tools, training, and high-quality, experienced systems engineers in key roles matter, especially for projects in highly complex and rapidly changing industry or mission contexts.
- Designing, using, and customizing processes that fit the needs of the project and the stakeholders lead to acceptance of SE expertise and increases value.
- Leaders, be they SE managers, project managers, or senior leadership team members, who champion the value of systems engineers and the systems engineering discipline within the organization, motivate and retain systems engineers while also enabling them to consistently deliver value.
- Given the global nature of most large-scale SE enterprises, it is important to use a global research approach to understand the geographic and cultural differences in: a) the perceived desirability and need for a dedicated SE workforce vs. a distributed SE expertise capability embedded in other roles; b) the perceived value of different teaming structures, decision practices (consensus, hierarchical, etc.), and approaches to constructive conflict; and c) preferences for pragmatic and situational approaches vs. preferences for structured and rule-driven approaches to problem solving.
- There is a need to incorporate more data analytics and quantitative models in the organizations, and that more effective SE processes be tailored to projects, which would help identify interfaces between disciplines and different parts of the organization.

To support individuals and organizations in implementing the findings of Helix, the team has developed two tools:

- Self-Assessment Tool – allows individuals to assess their knowledge, skills, and abilities as well as their career path, track progress over time, and set targets for development.
- Organizational Assessment Tool – allows organizations to set up their employees to provide data on organizational culture, structure, governance, and systems engineering. The tool provides basic analysis based on employee feedback and allows tracking of trends over time.

The tools as well as all major Helix findings and reports are posted to [helix-se.org](https://helix-se.org) to enable individuals and organizations to transition the research findings into practice.

## 1 INTRODUCTION

---

The US Department of Defense (DoD) and US Congress have a strategic interest in defining what enables exceptional product development and ensuring that the DoD can distinguish and manage its systems engineering (SE) workforce. As a University Affiliated Research Center (UARC), the Systems Engineering Research Center (SERC) was structured to conduct valuable research through collaboration with its sponsors to advance the state of the art in systems engineering – a key enabler of successful development.

A research agenda was formed around four thematic areas of interest by the SERC and its sponsors. The SE human capital development is one of the four areas that is relevant to this research task. The SERC's human capital research strategy is to reduce the professional development time of highly capable systems engineers and technical leaders, both within DoD and in the defense industrial base (DIB), and to improve the effectiveness of those systems engineers and technical leaders. It is also critical to have a baseline understanding of the SE workforce to determine the impact of SERC and other DoD human capital efforts to improve the workforce.

The overarching SERC research task is called **Helix**. When the Helix project began in 2012, the team was focused on investigating the DNA of an effective systems engineer. The team also found that organizations played a significant role in shaping and affecting the SE workforce. In 2019, the Helix team was motivated to expand the Helix project and study how organizations can become more effective at SE, including how they better enable their SE workforce. This is a fusion between the SERC Human Capital Development and Systems Engineering and Systems Management Transformation areas. The previous Helix work on individual systems engineers was a critical input to this project.

In the span of eight years, more than **650 individuals** from across **31 organizations**, with additional consultant interviews (not specific to a given organization), have participated in the Helix project through interviews and surveys. The qualitative analysis methods used in the past were inadequate to keep pace with the growing size of data accumulated throughout the years. The team explored new computational techniques such as data mining and analysis capabilities to allow the team to be more effective in analyzing and visualizing the rich dataset.

The Helix team also continued to gather qualitative and quantitative data from surveys on organizational culture, SE structure, governance and methods, processes, and tools; system engineering effectiveness; and teaming. This detailed data was paired with the interview data to identify critical relationships and organizational attributes that affect the effectiveness of the SE workforce. In 2019, 201 individuals from defense, aerospace, high tech, healthcare, and software organizations across the US, the Netherlands, and the UK participated in the Helix SE and peer surveys. Lastly, the Helix team developed an organizational assessment tool and updated the individual self-assessment tools to allow individuals to self-assess based on the proficiency (knowledge, skills, abilities, behaviors, and cognitions) and career path findings of *Atlas* (Hutchison et al., 2018 and Hutchison et al., 2020).

---

## 1.1 ABOUT THIS DOCUMENT

This document reports on the research findings from the research questions and Helix methodology. The major sections of this document include:

- 2: *Background*: This section provides an overview of the Helix project.
- 3: *Overall Helix Methodology*: This section provides a detailed description of the methodology used in this research project. The development of the survey and web-based tools are also elaborated.
- 4: *Helix Findings*: This section provides a description of the activities and findings from the research efforts performed throughout this period of performance.
- 5: *Discussion*: This section provides some general findings and other interesting topics from the data analysis.
- 6: *Conclusions*: This section summarizes the research performed by the Helix team.
- 7: *Recommendations*: This section provides suggestions and recommendations for reflection and for future researchers.

## 2 BACKGROUND

The Helix project began in 2012 to investigate what makes systems engineers effective. Since then, the Helix team developed *Atlas: The Theory of Effective Systems Engineers*. *Atlas* provided insights on what enabled individuals to be complex problem solvers by consistently delivering value to their organizations. The Helix team has been investigating these research questions and generated more than two dozen publications on Helix, eight technical reports, *Atlas: The Theory of Effective Systems Engineers*, an *Atlas Implementation Guide*, and an *Atlas Career Path Guidebook* (see Figure 1). The team also formed an advisory group (the Helix Advisory Panel or HAP) and held four workshops to discuss Helix research findings and plans.

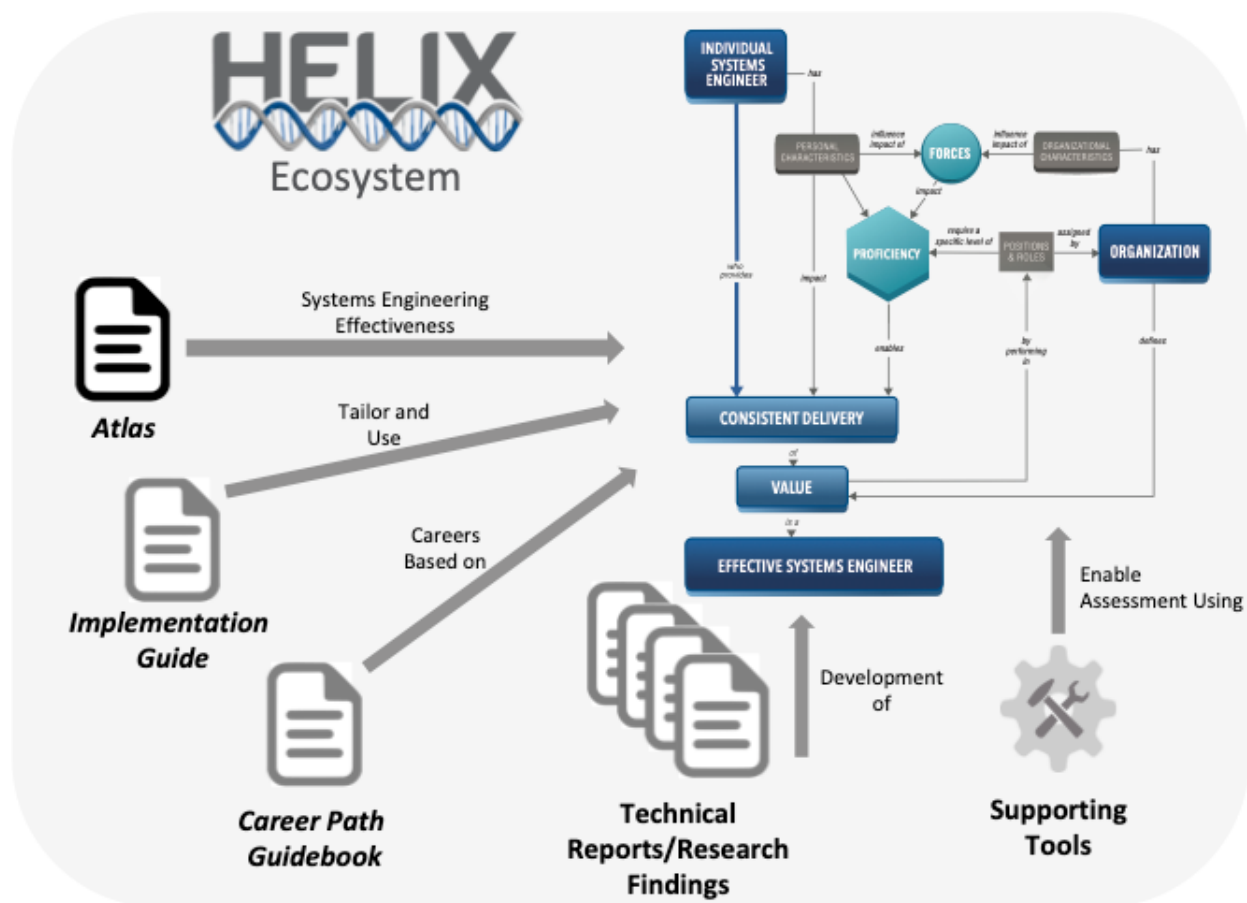


Figure 1. Relationship between Helix and Products Developed in the Project

Initial Helix research focused on gaining insights around systems engineers as individuals, which was reported in *Atlas*. Since 2018, the Helix research project centered on studying organizational attributes of teaming, culture, structure, governance, SE processes, and tools that systems engineers and other stakeholders reported as impacting SE organizational effectiveness (see Section 4.2). The Helix team set out to answer a new set of research questions focusing on what makes SE organizations effective or what may hinder them from being effective. The following are primary research questions around effectiveness:

- How can organizations improve the effectiveness of their SE workforce?

- **Why:** How does the effectiveness of the SE workforce impact the overall ability of an organization to successfully deploy increasingly complex systems and solutions (i.e., to have an effective SE capability)?
- **What:** What critical factors, in addition to individual workforce effectiveness, are required to enable SE capability? Factors include tools, practices, processes, policies, and culture. Engineering is a social event, so the means of aggregating individual capabilities is critical.
- **How:** How do the variables that impact SE effectiveness need to shift to enable different SE approaches? Given a specific situation, how can one evolve to a preferred operational outcome? This is not starting point independent.

Since 2019, the Helix team experimented by combining new computational and qualitative data analysis approaches to enable the development of a theory of what makes SE organizations effective. Section 3 provides the updated Helix methodology and efforts to expand the data collection with a focus on the culture, structure, teaming, and governance of SE organizations to identify patterns that make them effective. Considering that some of these organizations have large, complex internal and external systems, the team explored the bright spots as well as key tensions and challenges that the workforce dealt with while doing SE work in these dynamic environments. All the key findings are reported under Section 4 of this technical report.

### 3 OVERALL HELIX METHODOLOGY

---

The Helix project is a multi-year longitudinal study with a primary focus on understanding what makes systems engineers effective. The team designed a set of research questions and combined them with a ground theory approach using a mixed methods approach (Creswell and Plano, 2011). Grounded theory is a method in the social sciences for developing theory that is grounded in data collected and analyzed in a systematic manner (Goulding, 2002). The mixed methods approach refers to the qualitative and quantitative research methods. Although the initial data were collected from DoD and DIB organizations, the team interviewed non-DoD organizations to expand the data collection sample in 2015. The research resulted in *Atlas: The Theory of Effective Systems Engineers*, which is centered on the notion that effective systems engineers are those who provide consistent delivery of value (Hutchison et al., 2016). (Hutchison et al., 2016). *Atlas* has been updated and now reflects findings on systems engineers and systems engineering.

The aggregated data sources include interviews, survey responses, participants' resumes or curriculum vitae, and the organizational data from different artifacts from participating organizations. Interview participants were individuals who are doing SE work on programs, supervising systems engineers, using products from systems engineers, or are knowledgeable about the SE characteristics in their organizations. Follow-up interviews were also conducted to gather additional data for clarification or filling data gaps.

The organizational data include documents related to the purpose of the organization, its business and customers, information about the workforce in general or systems engineering, the demographics of the SE population, and organizational initiatives that may have an impact on systems engineers (Hutchison et al., 2014). Using qualitative analysis, the aggregated data from the interview transcripts or detailed summaries are reviewed and coded by the Helix team to find patterns of the research themes.

Since Helix began data collection in June 2013, a total of **487 participants** were interviewed, more than 201 individuals participated in the Helix surveys across **31 organizations**, and a group of consultants who had insights across a variety of organizations (see Figure 2). Interview participants who were willing also provided their resumes or curriculum vitae with details about their educational background and work experiences. Some of the interview participants were also invited to participate in the Helix surveys, which were launched in 2018. Follow-up telephone interviews were conducted with willing participants, to explore topics that could not be covered in the initial face-to-face interviews or to collect additional information based on their resumes. Follow-up interviews were also used to validate results of Helix analysis.

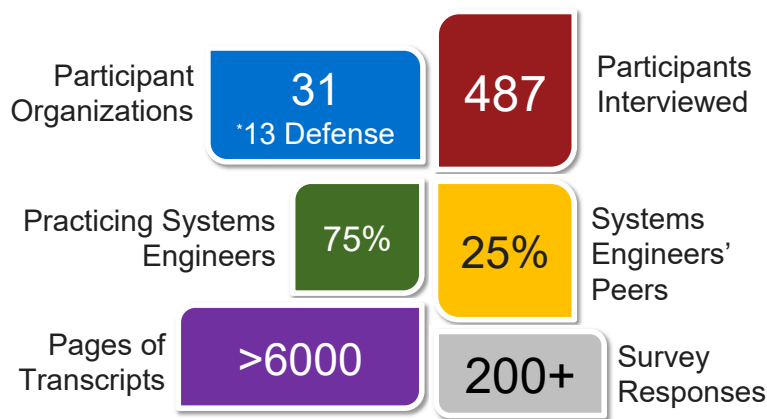


**Figure 2. Overall Helix Data Collection**

Figure 3 provides a breakdown of participants by domain. Nearly half of the individuals who participated in Helix currently work on defense systems. Roughly 10% of the participants work in industrial organizations that develop both defense and commercial aerospace systems; because both groups were interviewed and many individuals worked across areas, these are reported separately. The remaining participants are from across commercial aerospace, healthcare, transportation, telecommunications or information technology, or “high tech” companies that focus on complex technological advancement.

Another classification of the type of participant organizations is commercial affiliation. Helix classified commercial affiliation as: Government, and Industry and Federally Funded Research and Development Centers (FFRDC). As observed in Figure 3, more than half of the participants belong to industry organizations. The rest of the dataset is distributed among government entities and FFRDCs, the former covering roughly 30%, while FFRDCs make up roughly 10% of the sample.

From 2013 to 2019, 487 participants were interviewed from 31 organizations, as well as a group of consultants. Figure 3 shows the demographics of the interviewees. Interviews were in-depth discussions around what makes systems engineering effective either at the individual or the organizational level. The data was primarily analyzed qualitatively, though some data mining and natural language processing were applied.

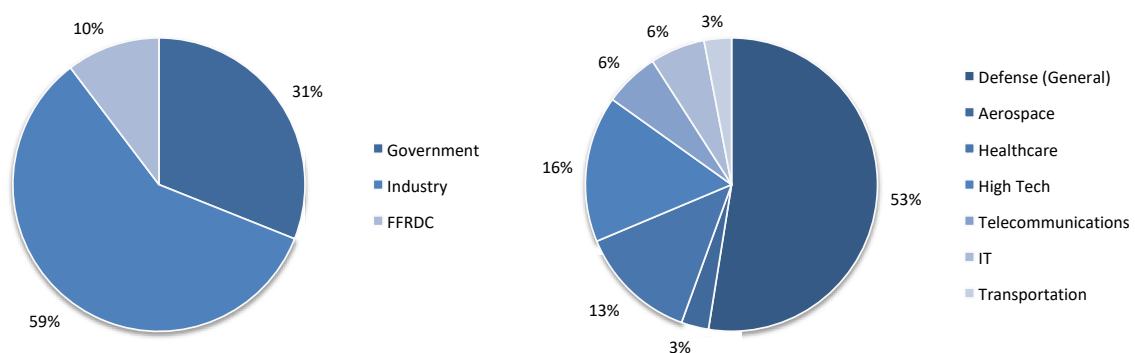


**Figure 3. Demographics of Helix Interview Participants**

In addition to the interviews, the Helix team used a survey for data collection specifically around organizational factors that contribute to or inhibit SE effectiveness. This survey included: two existing tools to study organizational culture (the Competing Values Framework and the Quality of Interaction Index); questions developed specifically around factors that interview data indicated were important for systems engineering related to culture, leadership, governance, structure, methods, processes, and tools; and finally, demographics. Figure 4 provides an overview of the groupings of the 201 survey respondents from seven organizations. Respondents were from the US, the UK, and the Netherlands. Numerically based survey data was analyzed quantitatively; free-text survey data was analyzed through qualitative and natural language processing approaches.

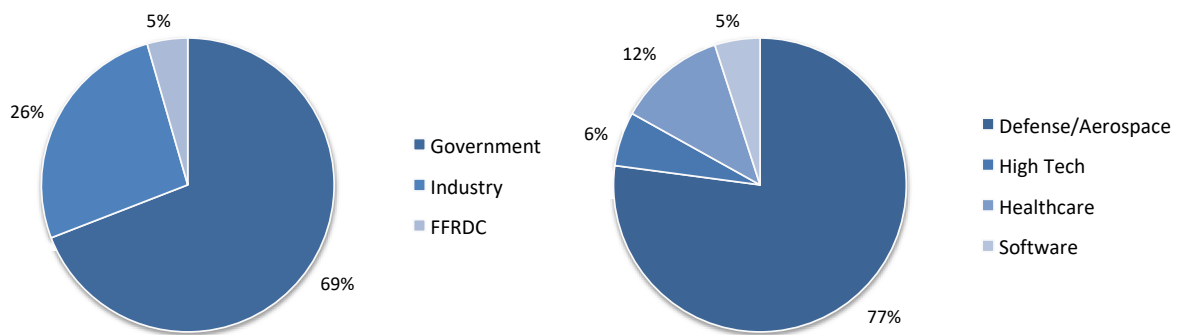


Figure 4. Demographics of Helix Survey Respondents

**Updated Research Methodology.** There were two paths for data collection from 2019 to 2020: (1) organization interviews; and (2) Helix surveys for systems engineers and their peers. The methodology for data collection from the interviews and surveys, as reported in (Hutchison et al., 2018 and Hutchison et al., 2019), remained unchanged. However, the team updated the research methodology to allow for various forms of data analysis and to utilize existing data in different ways.

### 3.1 WEB-BASED SURVEY

The Helix web-based surveys were designed with two parallel versions in mind: one for participants who are currently working in the SE capacity, and one for their peers, managers, and senior leadership – stakeholders of their work who could provide feedback on the information collected from systems engineers. The goal of the surveys was to evaluate the organizational attributes that support or hinder SE workforce effectiveness. The surveys contained both qualitative and quantitative data that were collected and analyzed by the team.

The team decided to conduct surveys because they provided clear and consistent data, although the surveys were limited by the rich context of interviews and open-ended discussions. In general, survey results were easier to analyze and enabled various types of analyses that were less time-consuming than qualitative data analysis. Anonymized individual surveys enabled respondents to share their personal thoughts of the organization and its culture. The survey data served as a reliability check on the conclusions drawn from the group interviews.

The two surveys had similar structures with slightly different wording to gather the opinions of these different groups on the same subjects. Using the Likert-scale and open-ended questions, the systems engineers and peers surveys were divided into four parts consisting of: demographic information about the respondents and their organization; a well-known culture assessment tool called the Organizational Culture Assessment Instrument (OCAI), which maps into the Competing Values Framework (CVF); questions focusing on SE practices and effectiveness, and their relationship to culture, structure, and governance; and a team behavior instrument called the “Quality of Interaction Index” (Qi Index) to examine the teaming within their organization. The CVF and Qi Index were both ideal instruments to investigate specific aspects of organizational culture and were built upon broad, global datasets that could provide additional context. Further descriptions of the CVF and Qi Index are available in Appendices C and D.

A pilot study was conducted during survey development to test the web-based survey. This pilot included 13 current and former systems engineers who were considered Subject Matter Experts (SMEs). Their valuable input was incorporated into the update survey and the team estimated approximately 45 minutes for participants to finish the surveys, depending on the number and extent of optional fill-in questions they completed. When an individual from an organization that also participated in Helix interviews completed the survey, they were provided an organization code; this enabled the team to link interview and survey responses. Names of organizations and individuals were recorded initially for internal use, but then deleted from the dataset to protect their identities.

---

### **3.1.1 SELECTION OF SURVEY SAMPLE**

Two types of survey participants were recruited: within organizations and at-large. Surveys completed within organizations contained an organization identifier to enable organization-specific data analysis and conclusions. Surveys completed by at-large participants were grouped together to look for general patterns across the SE community.

1. Within organization participants: All organizations recruited after July 2018 were given the opportunity to participate in the survey. Each organization determined who from their organization was eligible to complete the survey. Participation was voluntary. The Helix team encouraged organizations to distribute the survey link to systems engineers, their managers, peers, and other stakeholders of SE work. The Helix team also distributed the survey link to everyone they interviewed and encouraged people to share the link with others to increase participation.
2. At-large participants: Practicing systems engineers, managers, peers, and other stakeholders of SE work products were recruited at SE-related professional, industry, and DoD conferences and workshops. Participants were also recruited through professional organization newsletters, including the International Council on Systems Engineering (INCOSE) and SERC communications.

There were 201 individuals from nine organizations that participated in the surveys. Nearly three-quarters of the organizational participants were systems engineers, and

the remaining respondents were managers, peers, or other stakeholders, as seen in Figure 5.

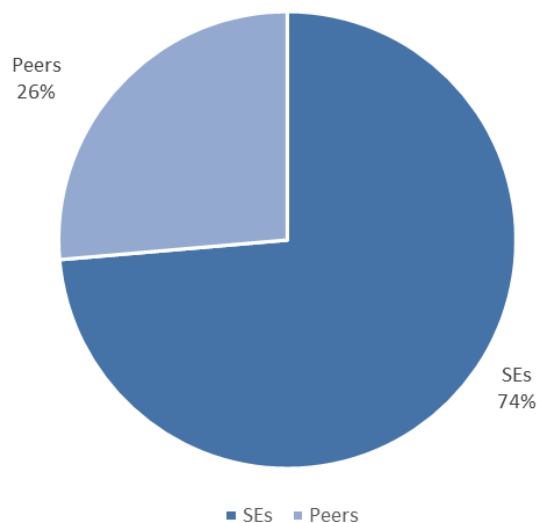


Figure 5. Survey Respondents

---

### 3.2 INDIVIDUAL ASSESSMENT TOOL

The team updated the web-based tools to enable individuals to assess their own proficiencies and career paths based on *Atlas*. The team implemented some changes to make the tools more intuitive and less defense/aerospace-focused so they can be broadly used in the SE community. Some of the wording and selective options for questions in the tools were updated as well. Individual systems engineers could utilize these insights to develop their own growth and development plans using insights from *Atlas*. If an individual agreed, the Helix team could use an anonymized version of this data for research purposes.

The Self-Assessment Tool was built using an advanced technology stack, which included Laravel and MySQL. Laravel is a well-known, open-source PHP framework used to build web applications. It helps to maintain an MVC (Model - View - Controller) architectural pattern and provides other features such as Eloquent ORM, Blade templating engine, Routings, Restful Controllers, Security methods, and others. MySQL is an open-source relational database management software. Figure 6 shows the updated self-assessment tool user dashboard displaying basic user information and the proficiency and career path assessments and results.

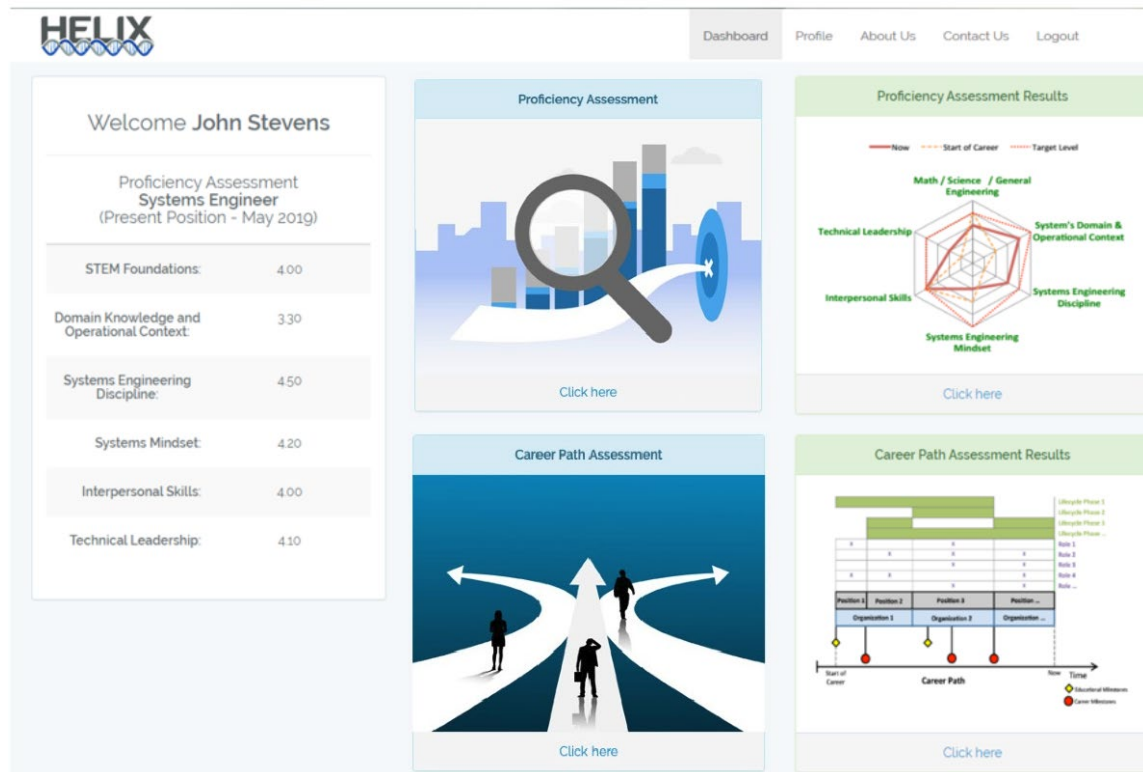


**Figure 6. Updated Self-Assessment Tool (User Dashboard)**

The Self-Assessment Tool is a Single Page Web Application (SPA), which uses Bootstrap, an open-source, front-end framework that enhances the application by providing a clean and easy-to-use user interface. Systems engineers can use this tool to assess their proficiencies and career paths in a more efficient and visually appealing manner. The proficiency assessment represents an individual's self-assessment on his/her knowledge, skills, and abilities in past, current, and future positions in six areas:

1. STEM Foundations (formerly titled as Math/Science/General Engineering)
2. Systems Domain and Operational Context
3. Systems Engineering Discipline
4. Systems Mindset
5. Interpersonal Skills
6. Technical Leadership

The individual will have to score himself/herself in each of the areas on a scale of 0-5 for every position, with 0 representing the least proficiency and 5 representing the most proficiency. The tool then uses this data to create a radar chart, which depicts the past, present, and future proficiencies of an individual. This enables the individual to keep track of his/her progress through each position. Figure 7 displays the proficiency assessment results in the form of a radar chart to provide a holistic view of the individual's proficiencies.

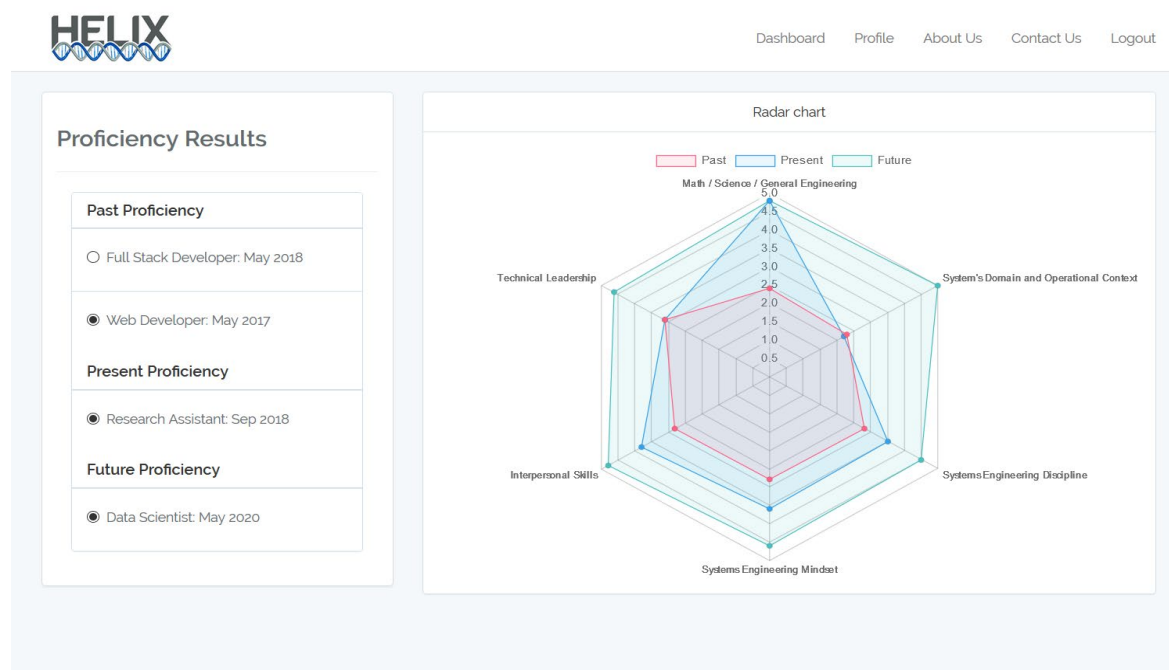


Figure 7. Proficiency Assessment Results

The tool prompts an individual to enter each position's Lifecycle Stages, Roles, System Types, System Scopes, and Domains; note, within this context, a career path consists of an individual's education, training, and experiences. The career path results are provided in a clear tabular form, as shown in Figure 8.

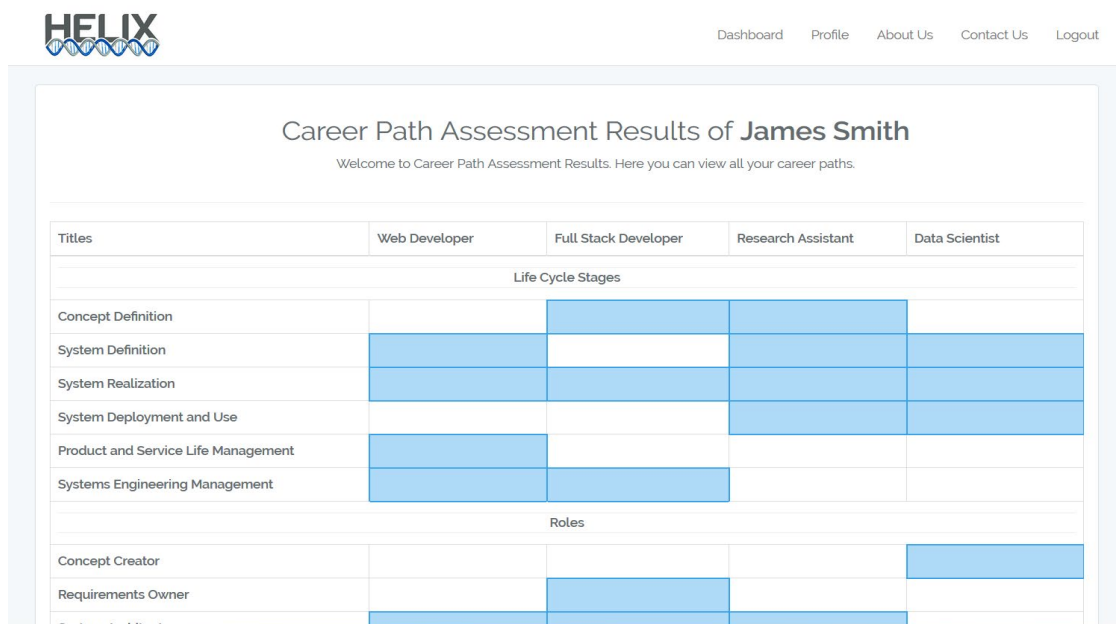


Figure 8. Career Path Assessment Results

The admin dashboard is an interface designed for the application administrator to view and manage the data collected by the tool, as shown in Figure 9. It provides the admin an overview of how the users of the tool are using the web application and allows effective oversight of the following:

- Number of users that have given consent for use their data
- Number of past, present, and future proficiencies entered into the system
- Number of current career paths entered into the system

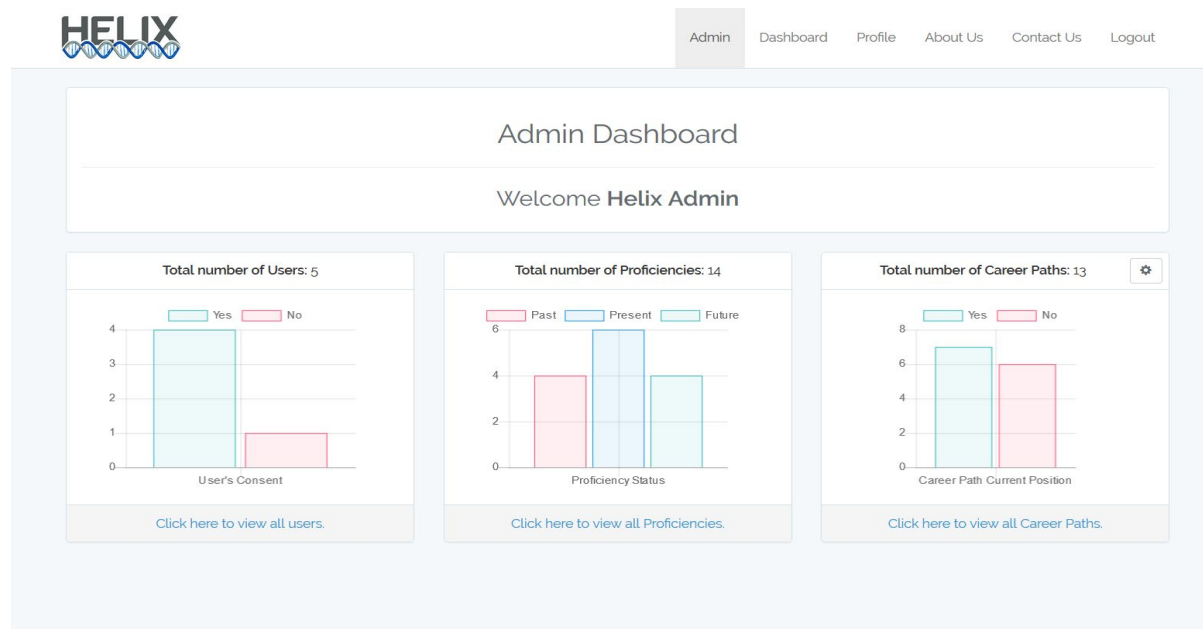


**Figure 9. Admin Dashboard**

The admin dashboard also enables performance of the following operations:

- View, update, or delete user's data
- View the proficiencies and career paths of users who have provided consent
- Edit the options and definitions in the Career Path Assessment Form

The self-assessment tool is currently available to the public on the Helix website:

<http://helix-se.org/participate>

### 3.3 ORGANIZATIONAL ASSESSMENT TOOL

Just as the Helix team has created a self-assessment tool for individuals to reflect mindful self-reflection and forward planning, in 2019-2020, team also created a tool for organizational to gather data on and plot their organizational SE effectiveness.

The organizational assessment tool was designed and developed as an expansion of the surveys conducted by the Helix team in Qualtrics. This tool enables users to complete the organizational assessment that contained both the Qi Index and CVF, as well as assessments related to culture, teaming, structure, governance, methods, and processes, and tools to enable effective SE capability. This tool allows organizations to gather insights from their SE workforce (systems engineers and their peers), and further analyze the data obtained.

The Helix team aimed for the organizational assessment tool to encourage reusability through accessible, easy-to-use design. The tool uses the mature Python-based,

open-source web framework Django that allowed construction of a website with low coupling, low complexity, and high reusability. For the database, the team used the relational database MySQL to efficiently manage the many structured survey results. The team also used Argon, which is a design system for Bootstrap 4 that enhances user experience. Figure 10 shows a screenshot of the organizational assessment questionnaire.

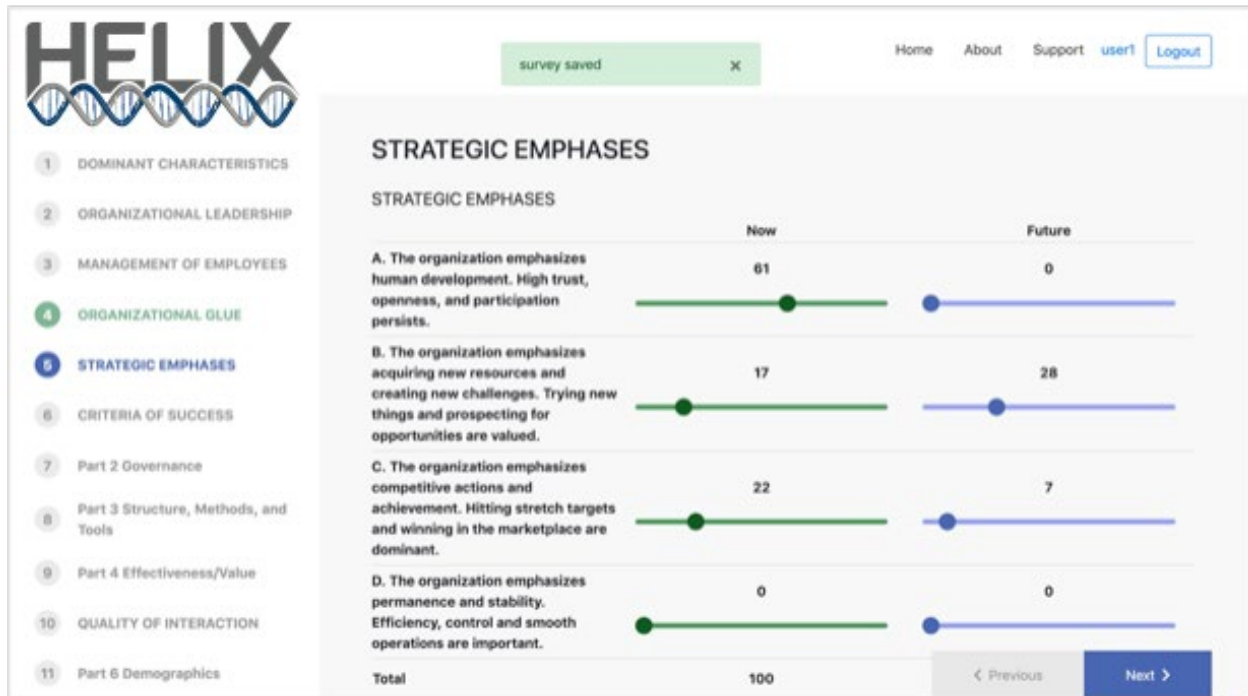


Figure 10. Screenshot of the Organizational Assessment Questionnaire

The team defined three users for this tool: users (those providing insights for their organizations), organization owners (those who set up and manage their own organizations), and administrators (those who control and update the tool, namely the Helix team). Following is a summary of benefits for each role.

1. *Users* can complete the assessment multiple times and view the assessments they have completed at any time. To enhance the user experience, the user can exit the assessment, which is saved, and continue to complete the unfinished survey at any time. Currently, there are two versions of the assessment: Systems Engineers and Peers. The differences between the two versions are not significant (limited to variations in wording that reflect the perspective of the type of user). Both assessment versions help users in different roles share their perspectives. Users can join through the token provided by the organization owner or create an organization and become the organization owner (see Figure 11).

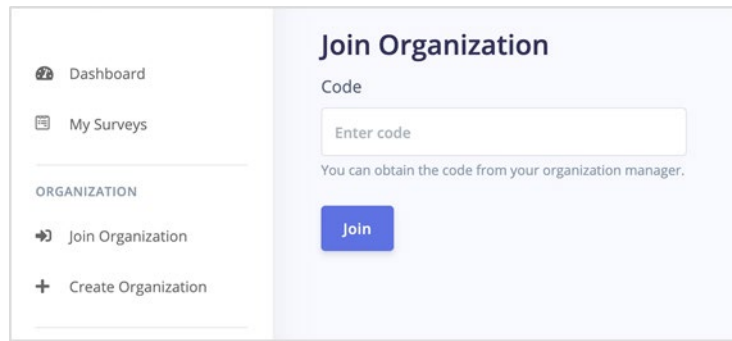


**Figure 11. Screenshot of User Interface to Participate in the Survey for a Specific Organization**

2. *Organization owners, leaders or managers* can view all participating members of the organization and their anonymized questionnaire results. The Helix team provided a data analysis module to help group organization owners, extract raw data (except personal identification information), and see the answers to each question, the number of users who completed the survey, the average value of the data, and the generated charts. The Helix team also provided a data export function to facilitate more complex analysis by organizations.
3. *Administrators* have a more powerful data analysis module and higher-level permissions that allow for viewing of all survey results. Administrators have the ability to analyze data based on different parameters such as organization, completion date, and participating roles (see Figure 12).

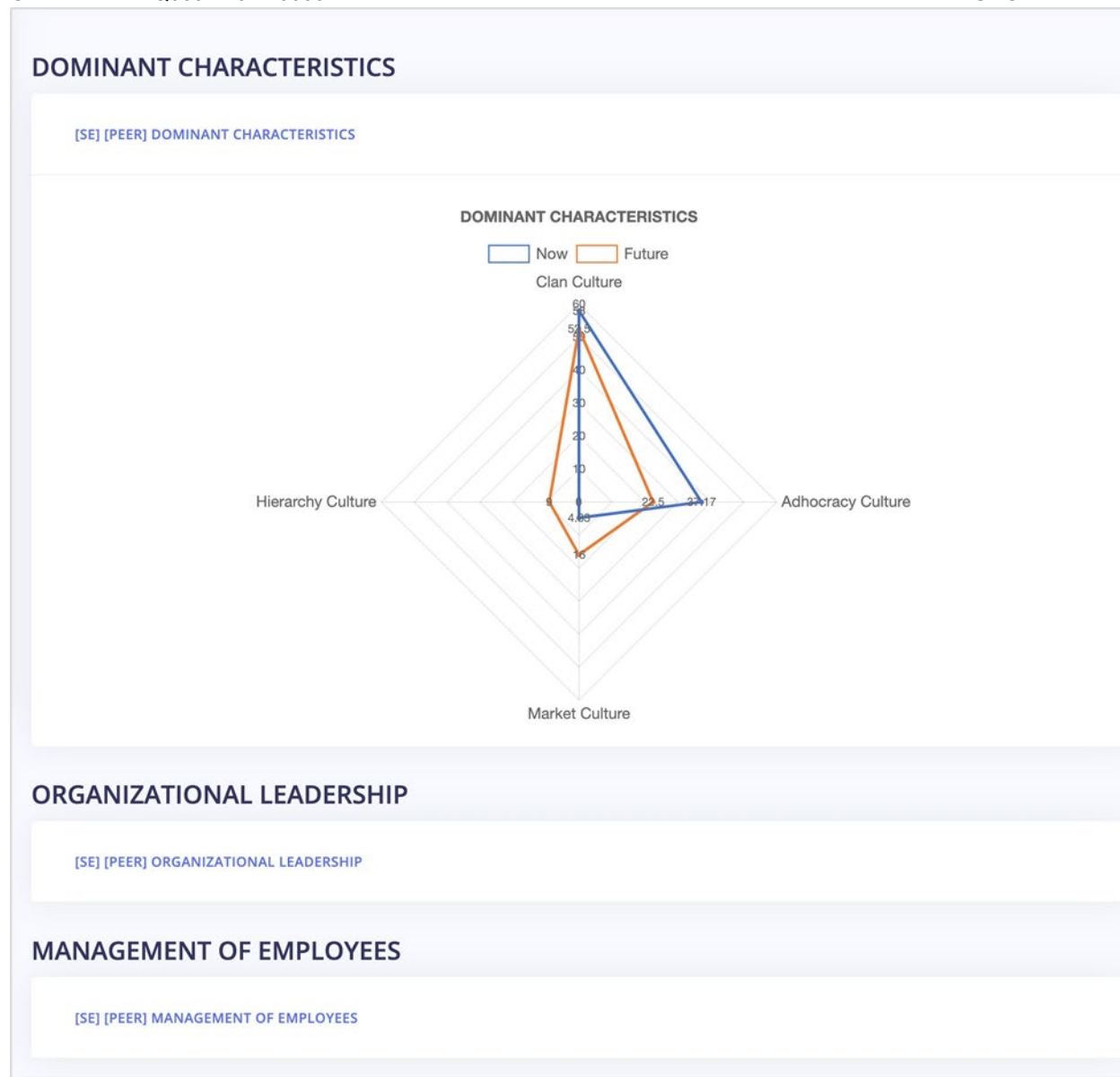


**Figure 12. Screenshot of the Organization Owner's Data Analysis Dashboard**

Note that this is slightly different in format from the CVF results shown in Section 4. The “diamond” shape is substantially easier to manage than the “square” shape traditionally used for CVF. If an organization would like to reach out to the Helix team for additional details, formatting this exactly in line with the CVF approach is also possible.

## 4 HELIX FINDINGS

---

In 2019 to 2020, the Helix team worked on gathering more data through site visit interviews and surveys to investigate individual and organizational attributes that influence the effectiveness of the SE workforce. The overall data collection efforts resulted in research findings on teaming, culture, structure, governance, methods, processes, tools, and other valuable insights that support or hinder SE workforce effectiveness. The team performed text analysis to gather insights through human validation of the qualitative and quantitative data. A SE analyzer dashboard was also developed as an experiment to explore the data. The following subsections provide the detailed findings from this period of performance.

---

### 4.1 ORGANIZATION ATTRIBUTES THAT SUPPORT SYSTEMS ENGINEERING WORKFORCE EFFECTIVENESS

The surveys were designed to gather detailed data and perspectives from systems engineers and their peers. There were 148 systems engineers who participated in the systems engineers' survey and 53 individuals who participated in the peers' survey. The questions in the middle of the survey were related to culture, governance, structure, SE processes, and tools. The results of key questions were incorporated and examples of data from selected organizations were reported.

---

### 4.2 SYSTEMS ENGINEERING EFFECTIVENESS

The second major lens on effectiveness is what it takes for an organization to have an effective SE capability. A capability is simply the ability to do something. Helix defines an "effective systems engineering capability" as the ability to perform systems engineering in such a way that the key values identified in *Atlas* are delivered consistently. Figure 13 provides the organizational lens of *Atlas*. It is important to note that the alignment of culture with leadership, governance, and methods, processes, and tools, is part of the equation of effectiveness. When these aspects of an organization are aligned, the organization overall is more likely to be effective in a number of ways and, likewise, misalignment reduces effectiveness. Specific to systems engineering, a culture that does not value systems engineering will result in less effective systems engineering. But, perhaps more importantly, an organization may state that systems engineering is critical, but have processes, a governance approach, and a teaming culture that does not empower or support systems engineering. Only when systems engineering is valued and different aspects of the organization are aligned to support the delivery of key systems engineering values is systems engineering effective.

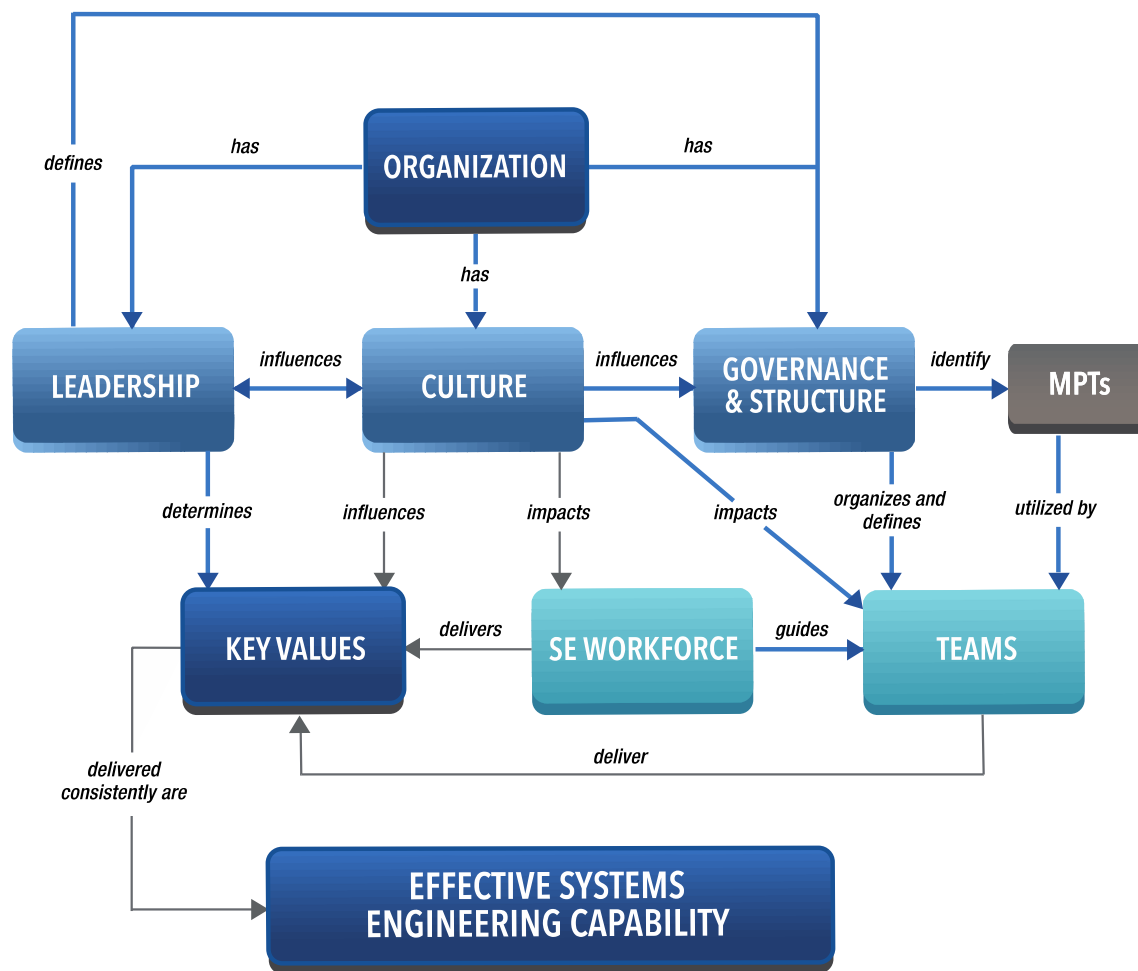


Figure 13. Organizational Systems Engineering Effectiveness

#### 4.2.1 SYSTEMS ENGINEERING-SPECIFIC SURVEY DATA WITHIN AN ORGANIZATION

The following example for the organization highlighted above demonstrates that for any given organization, the survey data provided overall perceptions of systems engineers, as well as information about the alignment of perceptions between systems engineers and others (Figures 14-15).

In the following three figures, there was some misalignment in the perceptions of systems engineers and others on how effectively they think systems engineering is organized in their projects (Figures 14-16). Across five different groups within the organization (corresponding to groups A-E in the cultural analysis), there were different views of the way the business organizes to perform SE. In Group C, others disagreed that systems engineering was effectively organized, while systems engineers in the same group had a somewhat more neutral view; it should be noted that there was a lower number of “other” participants in Group C and additional data points might change this view. Overall, however, systems engineers had a more neutral to positive view of the way systems engineering is organized compared to their peers.

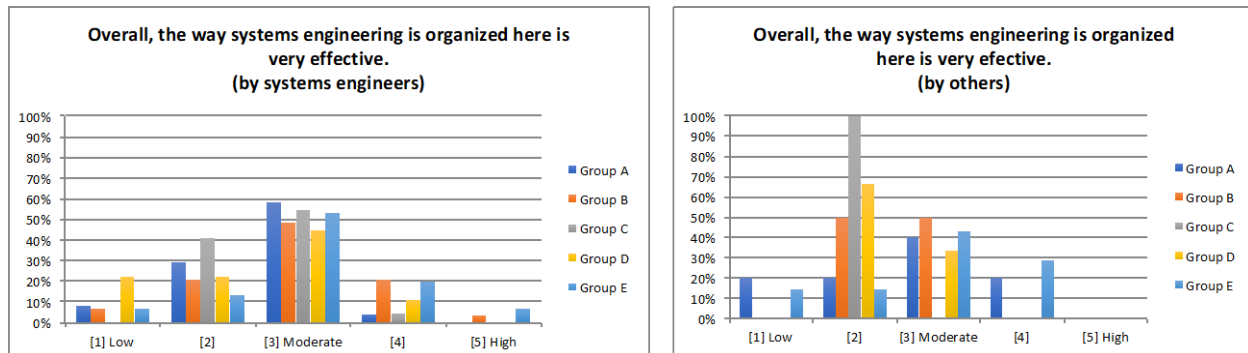


Figure 14. Within-Organization Ratings 1

In contrast, when asked how well systems engineers understand their roles in the organization (Figure 15), peers and others perceived less clarity, with responses trending negatively, while systems engineers' responses showed a more positive trend. One hypothesis is that there are differences in the values that systems engineers are expected to provide between these groups, which leads to a perception from others that systems engineers "don't know their role." There were no major differences across the groups, which aligns with the cultural assessments (above).

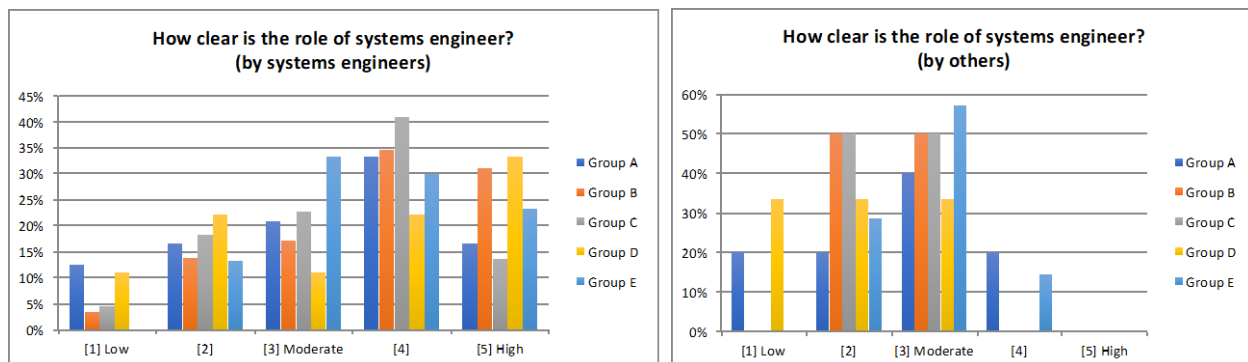


Figure 15. Within-Organization Ratings 2

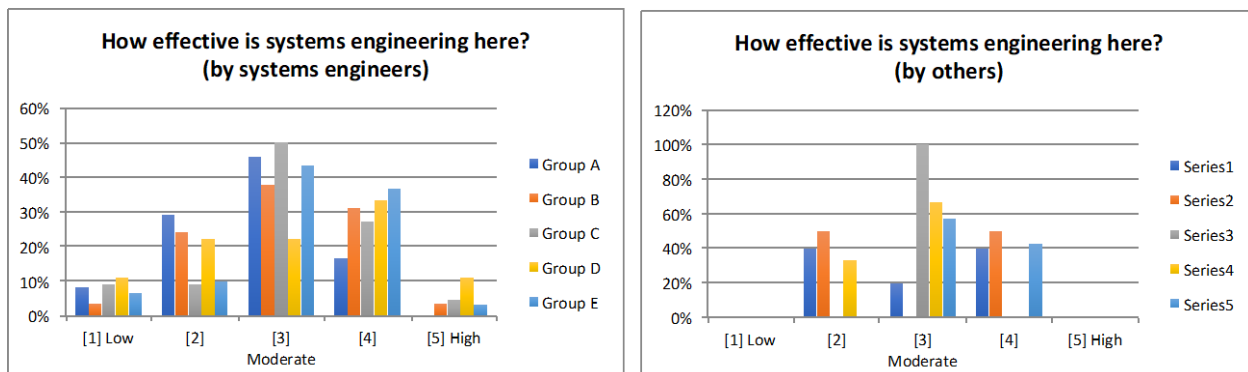


Figure 16. Within-Organization Ratings 3

Individuals were asked to rate the overall effectiveness of SE in their organizations (Figure 16). Others' ratings were more neutrally grouped, with no strong negative nor positive ratings. In terms of systems engineers, this is an example of why inter-

organizational comparisons are useful. For example, Group A has a more negative view of SE effectiveness than, for example, Group D. This provides an area that the organization can probe: what is going on differently in these parts of the organization? One hypothesis – that is confirmed by the Qi Index data – is that the subculture of Group D is more generative than that reported in Group A.

Looking at the CVF current and future data across four high tech industry organizations, it appears that systems engineers in even the most innovative companies perceive the need to become even more entrepreneurial in the future (see Figure 17). Analyses of the survey free-text and interview data provided a deeper understanding of the specific behaviors that companies perceived as essential to the success of SE in rapidly changing, highly competitive fields.

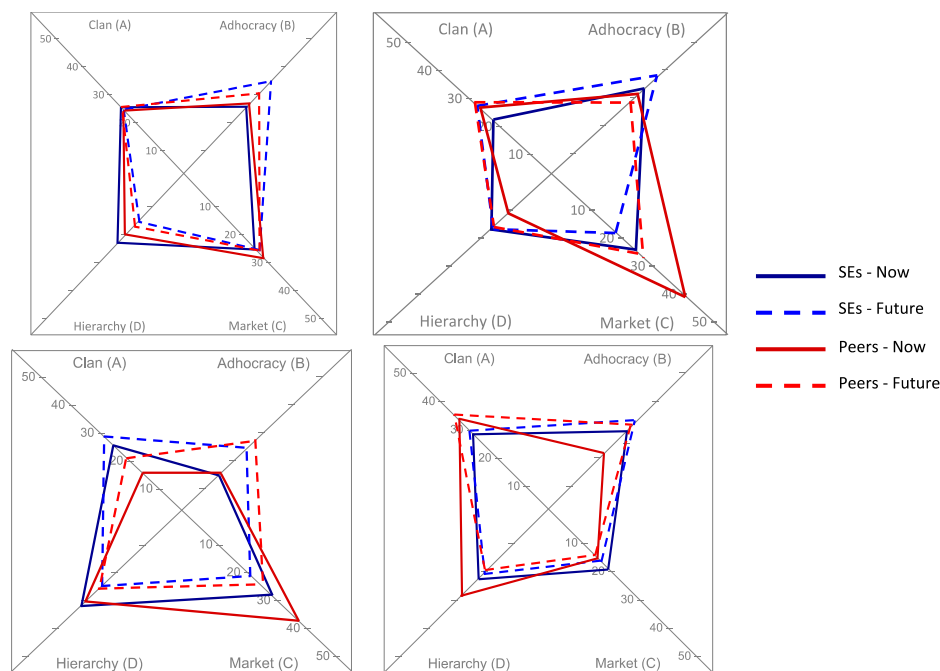


**Figure 17. Competing Values Framework Analysis of Four High-Tech Industry Companies**

### 4.3 SYSTEMS ENGINEERING GOVERNANCE, METHODS, PROCESSES, AND TOOLS

Systems engineering (SE) is often associated with methods, processes, and tools used to perform the work. The organization's leadership determines the governance and structure of its workforce, which is influenced by the organization's culture, and identifies the methods, processes, and tools (MPT) used by teams. The effectiveness, or the lack thereof, of SE methods, processes, and tools directly impacts an SE organization's workforce. The Helix team conducted a survey to investigate the effectiveness of SE governance, methods, processes, and tools. The survey consisted of five main questions on governance and nine questions on SE methods, processes, and tools within the organization. Participants were also encouraged to provide qualitative feedback with some of these questions.

The questions on SE governance and structure were related to the official roles in making key decisions, championing the SE discipline, and the connection of the SE

work to the overall mission of the organization. The effectiveness of the processes, methods, and tools of SE were also questioned in the survey. In addition, the survey solicited feedback on the effectiveness of the organization structure, effectiveness of the SE approaches and tools in the organization, use of leading-edge processes and tools (if any), and the perceptions of the systems engineers' skill levels. Both US and international organizations participated in the interviews and surveys, and their systems engineers and peers provided valuable insights for this research study.

All the responses from the interviews and surveys were integrated and summarized in an anonymized manner. In some questions, participants were asked to provide their rating from 1 (strongly disagree) to 5 (strongly agree) or "I don't know." There were also open-ended questions that provided participants an opportunity to share their perspectives. The summarized findings in this final technical report include their perspectives and were categorized by bright spots and tension points, as well as perceived needs for change.

In the survey, the participants were asked if they were using leading-edge SE processes and tools. The team found that the systems engineers' assessments of the leading-edge SE processes and tools received mostly negative or neutral ratings, which was rather concerning (see Figure 18). One of the respondents acknowledged that "the systems and processes are being worked up to leading edge, but they are not there yet."

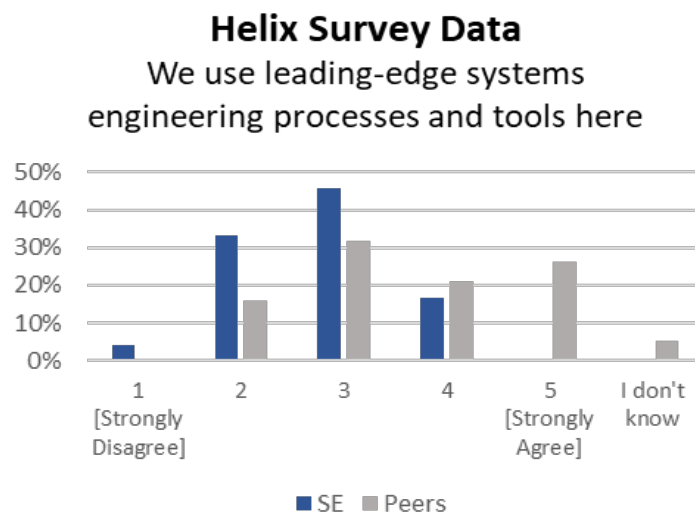


**Figure 18. Helix Survey Responses to the Statement**

**"We use leading-edge se processes and tools here (in this organization)"**

The following subsections provide detailed findings on the effectiveness of SE governance, processes, and tools across industry, government, and FFRDC organizations, and a case study on the effectiveness of SE processes and tools within a large government organization in the UK.

### 4.3.1 FINDINGS ON THE EFFECTIVENESS OF SYSTEMS ENGINEERING GOVERNANCE

The structure and governance of an organization is defined by the leadership and culture. They identify the methods, processes, and tools that are utilized by the SE workforce. The Helix team included questions in the surveys that focused on understanding the variables that may impact the effectiveness of SE governance. Some questions were related to systems engineers' official roles in making key decisions and championing the SE discipline, and the direct impact of SE work to the overall mission of the organization.

Figure 19 shows the quantitative rating results of the overall Helix surveys when the participants were asked to rate their perspectives on whether diverse thinking is brought to bear on important decisions in their organizations. More than 70% of systems engineers rated that statement from low to moderate, which indicated that they disagreed with that statement. One of the participants mentioned that "There is a gap in diversity."

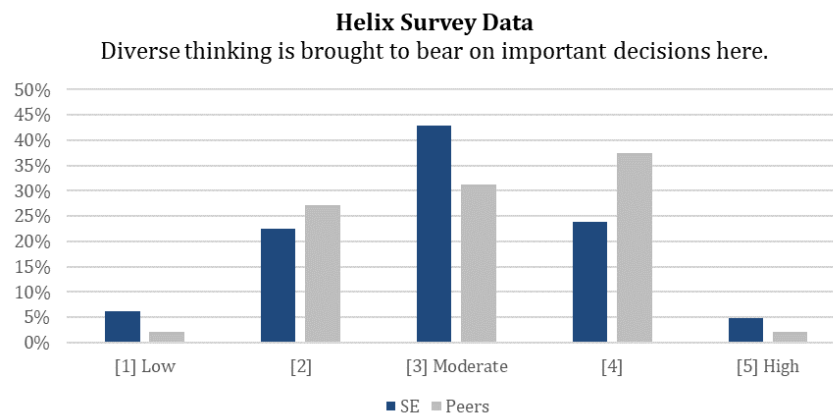


**Figure 19. Helix Survey Responses to the Statement**

**"Diverse thinking is brought to bear on important decisions here."**

The following bright spots and key tensions were highlights from both the interviews and survey data. Structure and governance variables such as limiting silo behavior and having a voice in the highest-level decisions may increase effective communication and data-driven decisions.

#### **Bright Spots**

The positive feedback on the effectiveness of SE governance from **government and FFRDC** organizations was summarized as:

- Systems engineers referee between conflicting groups. For example, they sort out the blame between hardware and software groups.
- Professional Development Group (PDG) enables shared knowledge and advice.

The positive feedback on the effectiveness of SE governance from **industry** organizations was summarized as:

- Decisions emerge, and they do not force a decision.
- Everyone, including higher management, has a right to be reviewed.
- Systems Engineering “always has an official and impactful role in making the important technical decisions.”

### **Key Tensions**

Interview and survey participants described hindrances to effective governance. In **government** and **FFRDC** organizations these hindrances included:

- Continuous turnover of staff and leadership was disruptive.
- Competency aligned organization minimized cross communication across functions and groups.
- Some projects do not have dedicated systems engineers, so the responsibility is shared across everyone.
- Systems engineers are technical leads, but there are pressures to maintain schedule and budget as well as manage the technical risk at the same time.
- A lot of program managers (who are systems engineers) slow them down, get in their way, create what they see as problems, and so they often bypass the systems engineer and go straight to the hardware or software lead; it creates tension and problems on the program. Good engineers who were trying to do the right thing were overruled by program managers and chief engineers.
- Ambiguity is also what systems engineers "own" vs. what they "influence".
- Having a separate division is helpful, but it causes an arbitrary split between parts of the SE functions that should work more closely. Subsystem systems engineering could be more closely stitched into the overall SE umbrella.
- “People in the government are paid to check boxes – you can build something that checks the right boxes that misses the point.”

The hindrances to effective governance described by **industry** organization participants included:

- Lack of clarity on the connections with the other business units.
- They need to be more functionally organized with more SE formality and more community.
- Projects are getting more fragmented as people work in their own circles and do not realize the impact on the whole organization.
- Systems engineers are perceived as making things easier, but the organization seems to make things more complex. Systems engineers are also viewed as a different discipline.
- Geographic dispersion, mixed roles, inadequate communication across roles, contradictory chain of command, and limited participation of stakeholders reduce effectiveness of decision making.

### 4.3.2 FINDINGS ON THE EFFECTIVENESS OF SYSTEMS ENGINEERING PROCESSES

In the surveys, the team asked about the availability of SE methods, processes, and tools to perform SE effectively. More than 70% of the systems engineers' assessments on the effectiveness of current SE processes were neutral or negative (see Figure 20). Only 28% of the systems engineers agreed that their SE processes were effective, which was an indicator that there were some concerns with the processes that may be affecting the effectiveness of the SE workforce.

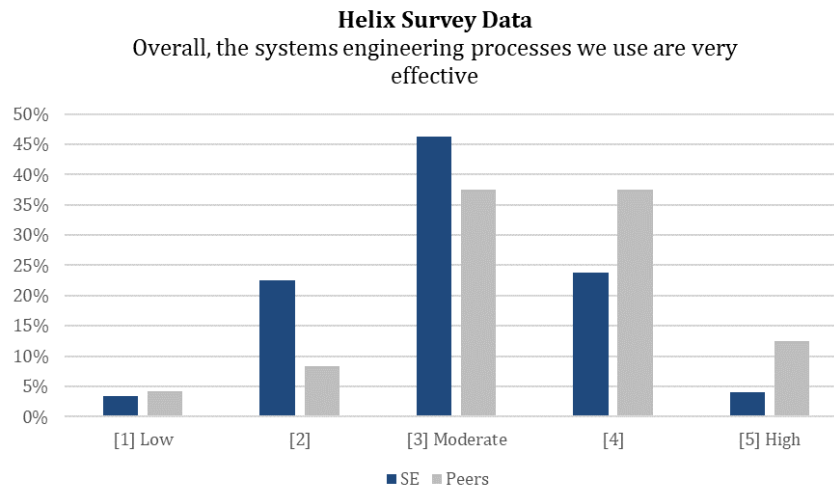


Figure 20. All Survey Responses on the Effectiveness of the Current SE Processes

To better understand some of the underlying issues or concerns from the quantitative survey data ratings, the team asked the participants to elaborate on their ratings of the SE processes. Below are summaries of participants' perspectives on the bright spots, key tensions, and perceived need for changes in the overall SE processes.

#### **Bright Spots**

The overall positive feedback on the effectiveness of SE processes from **government and FFRDC** organizations are summarized as follows:

- Having the right people for each process is integral to perform SE work effectively.
- Some organizations are beginning to focus on the importance of architecture and channeling more funding for architecture teams.
- The SE workforce is perceiving the use of Model-Based System Engineering (MBSE) as a vital part of their organizations. They are applying more MBSE tools and processes in their projects.
- The SE reputation is improving at higher leadership levels. Some systems engineers reported getting rewarded and recognized by senior leadership for their milestone achievements, which is motivating them to continue performing well as they felt appreciated.

- For government organizations, they reported that having contractors is improving their SE capabilities. In one of the organizations, they collaborated with private technology companies outside of the government, specializing in advanced technologies, which elevated their thinking. Fast iterations were possible because they had scientists, engineers, military operators, technology entrepreneurs, and others involved who were excited by the mission (most of these people were not there to earn a government salary, but they came because they were intrigued by the audacity of the mission).

The **industry** organizations provided their positive perspectives on the effectiveness of SE processes as follows:

- The processes help the systems engineers by clearly showing what they have to do and what their interfaces are to other teams.
- Systems engineers are free to tailor the prescribed processes to fit the project at hand.
- An effective approach is showing early working concepts/prototypes and validating this with customers reduces the risks early in the process.

**Overall key tensions and perceived needs for change were used in integrating survey and interview responses.**

### **Tensions**

In terms of the effectiveness of SE processes, the main organizational challenges impacting SE capability in **government and FFRDC** organizations were:

- The organizations are mission-driven, but part of the SE workforce lacks understanding of the tools, processes, structure, and/or have a weak requirements process.
- The frequent military leadership rotations and diversity of workforce (i.e., government, military, civilian contractors, etc.) impacts the knowledge transfer process. At times, the strong legacy culture and nascent SE new command governance have different views on the SE processes.
- In one of the organizations, the military-style decision-making approach is misaligned with the engineering-style decision-making process, which sparked tension in the SE workforce. Some systems engineers revealed that while they acknowledged the effectiveness of the SE processes, they may not always be recognized in major decision making. One of the participants directly stated that, "The decision makers should have listened to the engineers." They were clearly frustrated and there could be more improvements made to the decision-making process.
- There is tension in getting the right mix of agile and traditional SE practices and finding ways to intentionally customize that mix in different parts of the SE lifecycle. For instance, there was tension in mapping agile methods and quick prototyping from software to hardware development in an organization.

In terms of the effectiveness of SE processes, the tensions and challenges faced by **industry** organizations were summarized as:

- While MBSE is gaining popularity, only a few organizations seem to really know how to use it.
- The document-based systems engineering delivery is not keeping up with industry standards and we are lacking in requirements management.
- The functional breakdown does not fully reflect the physical breakdown of systems, which often lacks clarity due to the lack of ownership and other reasons.
- There could be more transparency in the processes between projects.
- There is tension with the V-model used in the project management plan and the growing use of agile processes in engineering work. The two processes do not seem to work well together.

### **Perceived Needs for Change**

For **government and FFRDC** organizations, some collective perceived changes suggested by participants were:

- Decision makers must have true appreciation for the **value** of systems engineers and **trust** them with the objectives, including making use of their rigorous analysis skills.
- There is a need to **increase use of data analytics and quantitative models**.
- Identify and manage interfaces between disciplines and parts of the organization.
- There needs to be **flexibility in SE processes** because some of the organizations are building one-of-a-kind products. There is no specific manual because they do not build many of the same type.
- The organization must **educate senior leaders on the value of systems engineering**, no matter what part of the industry or government these leaders come from.
- The organizations need to continue **building relationships and knowledge across boundaries**. This includes creating a safe environment that promotes the willingness and ability to speak up and voice their concerns without fear of retribution. The organizations should accelerate leadership or management engagement and follow-up appropriately.

For **industry** organizations, the perceived needs for change recommended by the participants were:

- When new SE processes and tools are introduced, provide systems engineers with some time, expertise to learn, test, and realize value of the new ways. **Provide systems engineers with more control to shave off excess procedures.**
- **Define shared requirements upfront to avoid integration challenges.** Ensure consistency, better alignment, clear vision, key performance indicators, and keep the systems engineers informed about what is coming.
- There needs to be an **end-to-end perspective at the beginning** of the process.

- Prepare for **systems evolution by adapting software architecture** and informing systems engineers about the existence of this architecture and the **usability of this in the SE design**.
- Some organizations tend to step into the pitfall that every project invents everything itself. That takes a lot of R&D effort to make and sustain. They would like to see **more synergy within projects**. For instance, **foster collaboration between software and SE** to gather the right specifications and create the right software.

#### 4.3.3 FINDINGS ON THE EFFECTIVENESS OF SYSTEMS ENGINEERING TOOLS

The effectiveness of systems engineers is influenced not only by the processes but also the tools made available to them. In the quantitative survey data, the team found that only 26% of the systems engineers agreed with the statement “We have the tools we need to do systems engineering effectively” (see Figure 21). More than 70% of the systems engineers disagreed or had neutral responses to that statement.

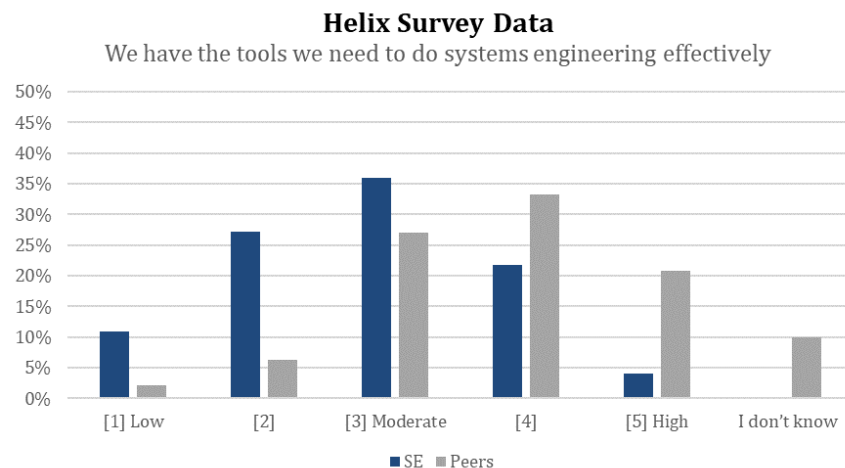


Figure 21. All Survey Responses on the Availability of Tools to Do Systems Engineering Effectively

#### 4.3.4 SYSTEMS ENGINEERING-SPECIFIC DATA ANALYSIS ON GOVERNANCE, METHODS, PROCESSES, AND TOOLS WITHIN AN ORGANIZATION

In a large government organization in the UK (referred to as Organization X), seven divisions (including systems engineers and peers) participated in the Helix survey that generated a large amount of free-text responses. When asked if they used leading-edge SE processes and tools in their organization, more than 90% of SE survey respondents rated that they disagreed with that statement, which was quite alarming (see Figure 22).

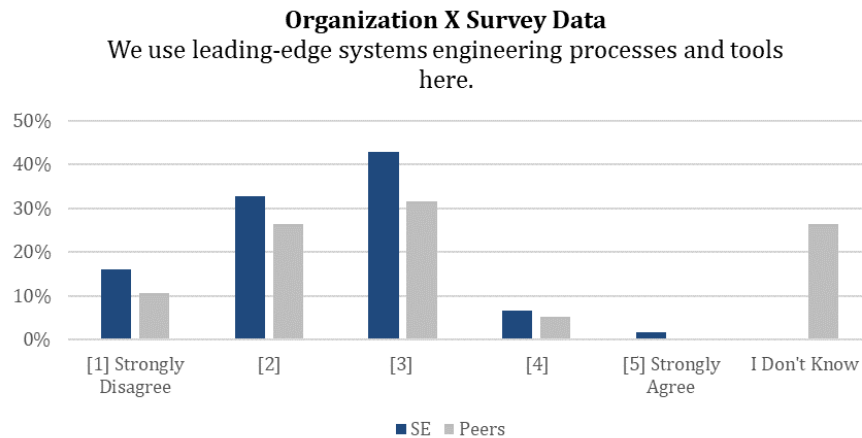


**Figure 22. Organization X Responses on the Statement**

**“We use leading-edge systems engineering processes and tools here”**

When asked about the effectiveness of the processes and tools, the respondents revealed some **hindrances**, including:

- The tools available are extremely limited and there appears to be **no clear plan for working out what else we need** and ensuring these tools are made available in a timely manner.
- Sometimes the **SE processes are too onerous** given the project size/complexity/output.
- There is **not a central resource from which to draw** (e.g., models and best practices within the organization), nor a high functioning network of systems engineers.
- There is **pressure to apply the minimum of process**—and to assume the supplier will be able to deliver these processes.
- We fund the SE tools, but they are administered by other partners. There is a **need to develop our own in-house IT infrastructure capability** and grow the talent.
- There are **no specialist tools available for most systems engineers**. Microsoft Office Suite is the limit for most. (Many people report having no tools.)
- There are **lack of available tools, knowledge, and training for MBSE** in the organization.

The respondents who provided **positive feedback** on the effectiveness of the processes and tools mentioned that:

- Their **effects are beginning to be felt across the wider project** scene.
- They could continue to remain compliant with regulations when they were given the **flexibility and freedom to change the processes**.
- With so many complexities across a vast range of capabilities, the various **assurance and governance roles play a vital part in ensuring continuity** of advice, commonality of approach, and overall coherence of outcome.

- Though the **processes have a reputation for being time-consuming, they believe that they add value.**
- The introduction of a new proprietary tool in the organization has had a massive impact on this, **distilling the various processes down into a single turn-key framework for coherent engineering delivery.**

Figure 23 shows the responses to the statement on the effectiveness of the SE processes, which indicated the systems engineers' and peers' survey rated responses are rather well-aligned.

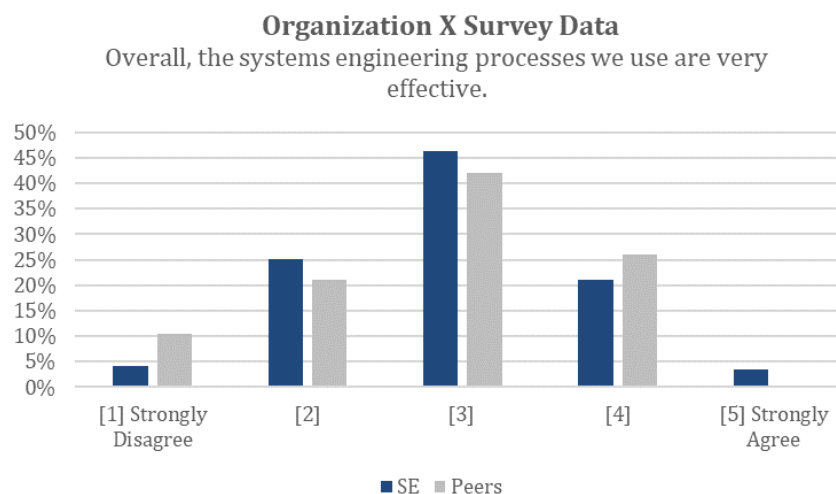


**Figure 23. Organization X Responses to the Statement**

**“Overall, the systems engineering processes we use are very effective”**

When asked if they have the tools needed to do SE effectively, Figure 24 shows that majority of respondents gave neutral or negative ratings, and some of their comments are described as follows:

- In the survey's free-text responses, many of the comments focused on areas of improvements for tools specifically discussed a **desire for tool integration** and for **tools that better support MBSE.**
- Some individuals mentioned that tools were either absent or out of date. Some participants also mentioned that they **lack the necessary tools to be effective** due to limited funding.
- Although some agreed that systems engineers have the tools they needed, they confided that **some systems engineers do not use tools because they lack the skills, training, guidance, experience and/or the process** that, as a result, inhibited them from using the tools.

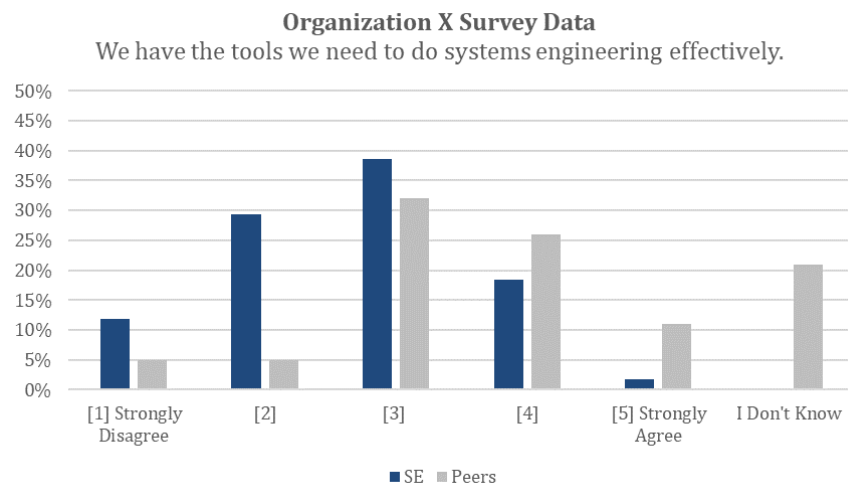


**Figure 24. Organization X Responses to the Statement**

**“We have the tools we need to do systems engineering effectively”**

In terms of the structure or governance of this organization, there were multiple SE pockets throughout the organization. While they expressed optimism that the current structure is improving and better than the previous structure, they revealed the following concerns about the structure or governance in this organization:

- The SE capability is in a silo and is not a fundamental aspect of the organization.
- There is limited influence at the higher level and SE is a “second class” function.
- Many do not see any organization of the function or believe there are clear roles.
- There is a lack of clear authoritative information as to where to go for agreement on technical decisions regarding specific topics or concessions.
- The hierarchy of decision-making is sometimes confusing, and no party wishes to admit to signing their name on decisions at a higher level.
- The delivery date is the top priority. Although they may not have the right people in the decision-making process, they were being forced to move on even if the design does not meet the requirements.

The perceived needs for change recommended by the participants in this case study were:

- Recruit, value, train, and retain the right people for each role.
- Improve organization-wide knowledge management to reduce "reinventing the wheel" each time when writing a requirement or management plan.
- Obtain a range of software for data modeling to bring along the SE community, with formal training for each application.
- Have dedicated SE leads in each area who have clear, responsible tasks and accountability.

---

## 4.4 CULTURE

The analysis of the survey and interview data is divided into two types: “within-organization” and “across organization” analyses. Within-organization analyses are performed to identify relationships between variables in each unique context and to observe consistencies and disagreements between systems engineers and others in each organization. These analyses enable participating organizations to understand the current state of their SE effectiveness and provide points for continued system-wide discussion and change. Across organization analyses enable the team to better understand patterns of variables that support effective SE overall and participating organizations to benchmark themselves.

---

### 4.4.1 CULTURE ANALYSES WITHIN AN ORGANIZATION

***Cultural Assessments within an Organization.*** Figure 25 shows the Qi Index data for a single organization that had seven divisions that included systems engineers (each color represents a different division). The leaders of this organization hypothesized that the cultures within each division would be very different from each other because the types of projects and parts of the product lifecycle each division was currently chartered to do were different. Although there were some differences in relative perceptions on some SE questions, overall, the cultures of the divisions were fairly similar. The overall culture was rated as having moderate cognitive diversity and low psychological safety, which resulted in an “oppositional” pattern for all divisions. The oppositional pattern is characterized by diversity of thought not being used well due to concerns about the risks of speaking up. Organizations with oppositional cultures tend to also have: unresolved conflict that drains energy; fragmentation, where people work in isolation; and stagnation, where failure to discuss and share ideas leads to low commitment and inaction (Reynolds and Lewis, 2017; 2018).



**Figure 25. Example from within an Organization with Multiple SE Divisions**

Figure 26 from the Qi Index report for this organization, depicting the most common descriptors from participants, gave further insight into the operating culture in terms of behaviors, emotions and states observed. In this case, the hierarchical, cautious, conforming nature of the culture relates to feelings of constraint and fatigue consistent with a highly bureaucratic way of operating.

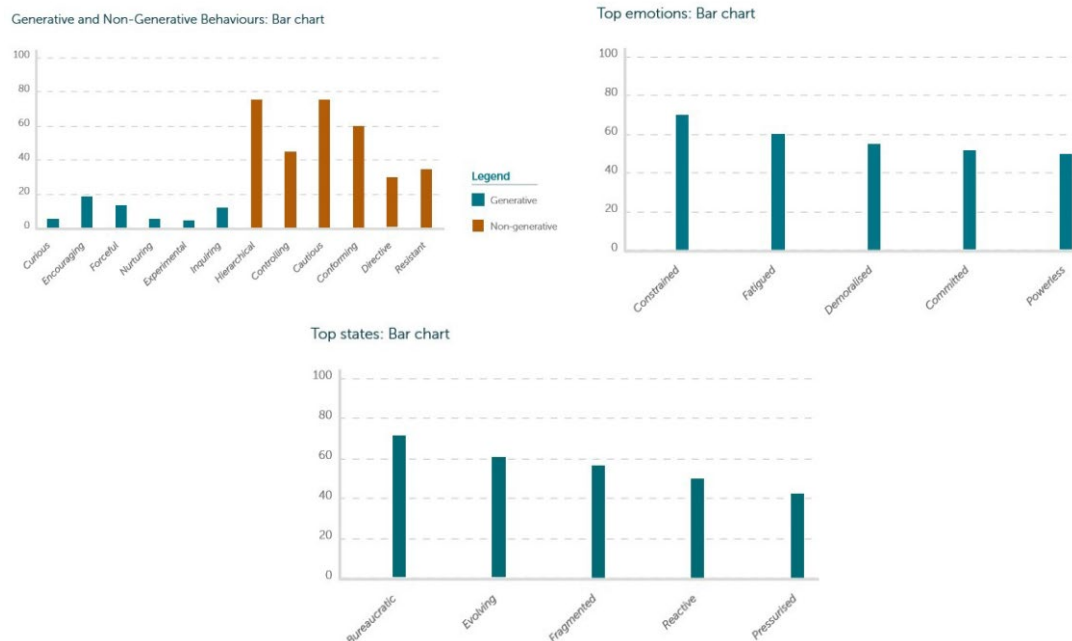


**Figure 26. Within-Organization Qi Index Analysis of Organizational Behaviors, Emotions, and States**

These Qi Index data are consistent with the CVF data for this organization as shown in Figure 27. The participants in this organization describe the culture as very hierarchical. They see a need to change towards the adhocracy quadrant in order to increase innovation and agility. Taken with the Qi Index data, the organization now has a clear view of the cultural constraints that may hinder effectiveness. Although these data may not be a surprise to the systems engineers in the organization, the use of standardized instruments to depict what is going on can influence leaders to devote resources for change. Deeper analysis of the Qi Index data was conducted by grouping the descriptors by scores on SE survey questions. Observations about the relationships between the Helix survey's two effectiveness-related questions and the Qi Index descriptors in this organization include:

- The top five words for feelings, behaviors, and states change for high and low effectiveness ratings and for detractor versus promoter ratings. For example, feelings of being demoralized and constrained show up in the top five words for all categories of perceived effectiveness, but the people who rate the organization effective feel secure and involved.
- The behaviors of hierarchical, cautious, and conforming show up in the top five at all levels of perceived effectiveness, but those who rated SE as more effective also see behavior as reasoned and resourceful.
- People who think SE is ineffective do not see the organization as evolving, while people who rate SE as effective don't see the organization as fragmented (as do neutral and low effectiveness respondents).
- On the Detractor-Promoter question, "Would you recommend that a systems engineer you are friends with work here?", Promoters and Passives list feeling "committed" among the top five descriptors. Promoters feel secure, appreciated, respected, and engaged, descriptors that don't appear among the top five for Passives or Detractors.
- As for behaviors, Detractors, Passives, and Promoters all list cautious as a behavior among the top five, while Promoters and Passives also see encouraging behavior, and Promoters see respectful and inquiring behaviors.
- As for the state of the organization, Passives and Promoters view the organization as improving, while Detractors do not. Everyone lists "evolving" among the top five; everyone notices the changing environment, but only Promoters and Passives view that change as positive (improving).

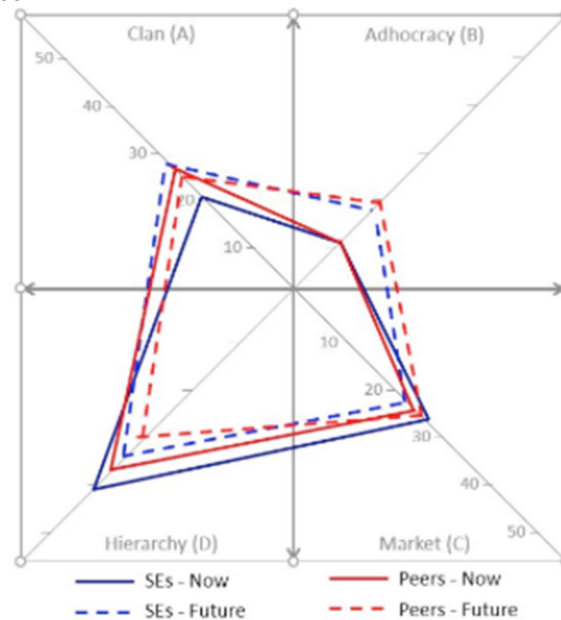


Figure 27. Within-Organization Competing Values Framework Data

**Integrating Interview Data with the Competing Values Framework (CVF) Data within an Organization.** The CVF inventory uses a standardized set of questions to find patterns within organizations. Because it uses the same questions for everyone in the sample, it is a reliable indicator of the current views of the people in the organization and can be used to track changes over time. Since not all organizations will do a formal survey, the Helix Team compared the qualitative interview data with the more quantitative based CVF data. Table 1, below, shows the comparison of CVF data for Organizations A and C. The qualitative data obtained through interviews supports the CVF findings and can be used to get a general understanding of perceptions if analyzed using the general CVF framework—if the formal survey cannot be administered.

**Table 1. Culture Descriptions for Interview Data Sorted into Competing Values Framework Quadrants for Organization A**

| <b>Organization A: Culture as Described in Interviews</b>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              |
|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <b>CLAN QUADRANT - COLLABORATE</b> <ul style="list-style-type: none"> <li>• Personal ownership is a governing principle.</li> <li>• Transparency is what gives you control.</li> <li>• Make sure people who make decisions and do the work are connected.</li> <li>• Consensus as a cultural trait – score high on femininity as a cultural skill, more than others.</li> <li>• We treat each other like family.</li> <li>• A lot can be said openly without repercussions.</li> <li>• We try to put a mandate as low as possible.</li> <li>• Get collective intelligence maximally used.</li> <li>• Co-located, cross-functional teams create a bubble.</li> <li>• Consensus, but we could decide what not to do better.</li> <li>• They're ready to invest in people.</li> <li>• Communication between projects is limited.</li> </ul> | <b>ADHOCRACY QUADRANT - CREATE</b> <ul style="list-style-type: none"> <li>• We create ownership by delegating challenging goals to people who have the freedom, without boundaries. We don't fail, we learn.</li> <li>• We're a learning organization; otherwise we can't innovate.</li> <li>• We are a tribe of innovators. We like to take a big step, try new things, be different.</li> <li>• SEs in charge of handling dilemmas – when logic alone doesn't get you there – perception, feel.</li> <li>• We look for curiosity in SAs.</li> <li>• We have a lot of inventions in our product that no one has.</li> <li>• Our identity is in question: do we want to be different or better? Do we want to be an integrator or have unique technology?</li> <li>• We do really well building and testing risk-oriented prototypes.</li> <li>• This is a technology playground.</li> </ul> |
| <b>HIERARCHY QUADRANT - CONTROL</b> <ul style="list-style-type: none"> <li>• Parent company cares about process repeatability, not a match with us.</li> <li>• We cannot even imagine getting tasks assigned.</li> <li>• SA is a role, not a position. No formal functional organization.</li> <li>• We're varied in types of tooling and processes – similar deliverables but the process we use to get these deliverables aren't the same.</li> <li>• Depend a lot on local heroship. You get the result by the person you put there. Needs change to</li> </ul>                                                                                                                                                                                                                                                                       | <b>MARKET QUADRANT - COMPETE</b> <ul style="list-style-type: none"> <li>• We measure SE effectiveness by the business: can we materialize the value into profit, and what is the customer feedback?</li> <li>• We're business-to-business, so don't really see the very end customer.</li> <li>• Customers recognize that we make green-button, complex machines that are simple to use.</li> <li>• Is the point to be different or be better? I think that a little more concern about competitiveness and comparison to others would be good. We go on customer visits</li> </ul>                                                                                                                                                                                                                                                                                                          |

| <b>Organization A: Culture as Described in Interviews</b>                                                                                                                                                           |                                                                                                                                                                                                                                                                                                                                              |
|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <p>move to product lines – multiple heroes in parallel. Single project approach in our genes.</p> <ul style="list-style-type: none"> <li>We fall into pitfalls: every project invents everything itself.</li> </ul> | <p>but not well organized.</p> <ul style="list-style-type: none"> <li>Very big pressure in projects to deliver something to market, then we sometimes forget we could work together to come up with a solution together for both projects.</li> <li>Mentality: there is only one project – this one! Suffer from Project Passion.</li> </ul> |

As shown in Table 1, compared with Figure 27, people described the Organization A culture consistent with the scores they gave on the CVF. This culture is well known by all and perceived similarly across systems engineers and others within the organization. In the case of Organization C, note that the mixed messages in all quadrants reflect the dispersion of CVF results found in that organization (see Table 2).

**Table 2. Culture Descriptions for Interview Data Sorted into Competing Values Framework Quadrants for Organization C**

| <b>Organization C: Culture as Described in Interviews</b>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                |
|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <p><b>CLAN QUADRANT – COLLABORATE</b></p> <ul style="list-style-type: none"> <li>We're open, but some siloed behavior. (You're V&amp;V and you're Software.)</li> <li>Moving to a more open, transparent cross-functional culture.</li> <li>Knowledge matters.</li> <li>When there is a problem, we want to help.</li> <li>No room for failure. When it's good, open and transparent; when things go bad, closed and siloed.</li> <li>We swap people to get around silos.</li> <li>Interventional Applications has a more open culture.</li> <li>So many stakeholders and people involved sometimes prevents us from releasing products faster.</li> <li>We have no doors. Someone five levels above sits next to me.</li> </ul> | <p><b>ADHOCRACY QUADRANT – CREATE</b></p> <ul style="list-style-type: none"> <li>Effectiveness: Internal innovation prize for the product, especially if on a different stage in different area of the world – Bangalore – with people from all over.</li> <li>An example of effectiveness last year: we chose technical solutions that are right for future – we had the guts to deviate from company policies to benefit our system. Courage.</li> <li>Architects constantly refresh roadmaps, incorporate feedback.</li> <li>We use standard process to create products – but don't have process for bringing in ideas for investing in Systems Architect/Systems Designer (SA/SD) tools.</li> <li>Fact-based culture: go out and get the facts.</li> </ul> |
| <p><b>HIERARCHY QUADRANT – CONTROL</b></p> <ul style="list-style-type: none"> <li>Strive for predictability over the long term – three years from now.</li> <li>I see effectiveness of SE as: architecture enables modularization and reuse; and no</li> </ul>                                                                                                                                                                                                                                                                                                                                                                                                                                                                   | <p><b>MARKET QUADRANT -- COMPETE</b></p> <ul style="list-style-type: none"> <li>We are results-driven.</li> <li>High sense of commitment to keep this important business unit successful.</li> <li>We're cash cow but still growing.</li> </ul>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                |

| <b>Organization C: Culture as Described in Interviews</b>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             |
|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <p>nasty surprises, no unexpected delays, no complaints from field.</p> <ul style="list-style-type: none"> <li>• Execution needs to be more effective.</li> <li>• The plan is still valid from three years ago, just shifted four years.</li> <li>• We have a biannual process: architects constantly refresh roadmaps, incorporate feedback.</li> <li>• Applications: struggle to simplify QMS used for large systems to our needs with process owners.</li> <li>• Regulated business very process heavy; overhead.</li> <li>• Larger corporation focus on agility - a tension point here. Still on journey with Lean.</li> <li>• “We tried it before and it didn’t work”, “We’ve always done it this way.” Need more “let’s give it a try” open-mindedness.</li> <li>• “Great” would look like no surprises, predictability, no chaos, go to right stakeholders, ID tech risk early, early us.</li> </ul> | <ul style="list-style-type: none"> <li>• Delivering on time is more important than delivering good quality when the pressure is on (not all agree).</li> <li>• PM is saying, “Time, time, time”; Dept Manager saying, “I need right quality.” Expect SEs to step up and say, “I won’t deliver with this bad quality.”</li> <li>• We budget short-term, affects long-term architecture.</li> <li>• I define SE effectiveness as: if you can create products that are better than the competition but also in a way that can sustain that leading position.</li> <li>• Our plans are ambitious.</li> <li>• We capture user needs, but SA/SD still a distance from the market.</li> <li>• Have a formal and an informal way to get user’s needs.</li> <li>• It annoys me that we don’t know how our system is used in the field. Need performance metrics on features to kill them.</li> </ul> |

**Overall key tensions and perceived needs for change were used in integrating survey and interview responses.**

### **Tensions**

The Helix team found that the **industry** and **FFRDC** organizations in the sample experienced similar tensions. The five most common challenges affecting SE capability in these organizations are:

- System complexity requires different skills, tools, and strategic approaches than currently commonly available. These organizations find it difficult to hire systems engineers with cutting-edge knowledge and tool experience, and often don’t have the time, money, and expertise to acquire the tools they’ll need as systems get even more complex and schedules get shorter.
- Many of these organizations struggle with finding the balance between investing in platform development and focusing on the immediate and unique needs of individual projects. SE organizations “know” they need better road maps and reuse of designs, but often do not have the organizational backing to invest time and expertise in forward planning and integration.
- Although most organizations believe MBSE is important, many feel MBSE is not well understood within and across functions. Early implementations of MBSE

have not always demonstrated the full value of the approach and teams have had difficulty getting buy-in from developers to make full use of the methods.

- The “agilization” of software has become an expected and valued approach to software engineering, but now companies struggle to make similar speed and flexibility advances in hardware domains. This is seen by many as the next frontier for complex system design, and delivery and people are looking to SE to advance the cause.
- In several of these organizations, software has become more central to products of all kinds. Systems engineers, however, often come from hardware backgrounds and do not have the experience or depth of knowledge needed in software. Similarly, leaders of SE organizations typically have hardware engineering backgrounds and are seen as not adapting to the changing priorities of software/hardware development.

The team observed that **government** organizations experienced a different set of organization tensions. These include:

- Constant changes of personnel undermine efficiency, and the quick succession of leaders undermines clarity of the mission on projects that require long-term focus.
- Systems engineers believe that schedule focus overrides using important SE processes, limiting SE contributions and jeopardizing the quality of the products.
- Often there are two very different mindsets simultaneously in operation on a project that cause conflict. The military or operations mindset values speed and action and conflicts with the SE mindset that values data-driven decision making, process integrity, and testing. Governance decision-making approaches are seen as being stacked against quality systems engineering.
- In the government organizations studied, systems engineers did not feel respected, valued, understood or championed, in part because of the conflicts identified above.
- Given the common practice of government projects using contract organizations for critical components of the products, they sometimes struggle to maintain internal SE skills when most of the SE work is being done by contractors. SE excellence is necessary in the government organizations to ensure systems-of-systems integrity and provide direction for the contract SEs.

### **Perceived Needs for Change**

The free-text and interview analyses also identified different perceived needs for change among the industry and FFRDC organizations and the government organizations.

For the **industry and FFRDC** organizations, the most common changes recommended by participants include:

- Need to invest in tools, training, and rotations for systems engineers, especially on MBSE.
- Do platform and cross-project road mapping using systems engineers at the start of all new projects.
- Keep pushing down the hierarchy and increasing empowerment of systems engineers by educating managers and peers on SE expertise and value.

- Reach out to other organizations (internal and external) that are a few steps ahead on new approaches; find ways to constantly learn as the field and the complexity of projects change.

For the **government** organizations, the most common changes recommended by participants are:

- Increase empowerment. Though this was also said in industry, it was said ten times louder in government. (Companies in the Netherlands described the greatest empowerment in the sample, suggesting some broader cultural differences.)
- Keep key people in place and invest in knowledge transfer for people who must rotate in and out of a project.
- Make data-driven decisions on realistic schedules.
- Redesign the SE processes to be faster and more customizable for different kinds of products, and of high value for other functions as well as for the customer.
- Promote forward-thinking, openness to change, and systems thinking mentalities, and demonstrate through action why these mindsets make SE critical to the success of the product.

#### 4.4.2 CULTURE ANALYSES ACROSS ORGANIZATIONS

Looking across organizations in the total dataset, the data show that in some organizations, there was strong consistency in perceptions across SE respondents—e.g., organizations L86 and J31 in Figure 28—while in others, there is a much higher variability in the perceptions of systems engineers, e.g., organizations M85 and L12. In Figure 28, the overall status of systems engineers ranges from neutral to positive across the participating organizations. The J31 and L86 responses were from small sample sizes, so the 100% is reflective more of the sample size than cultural alignment.

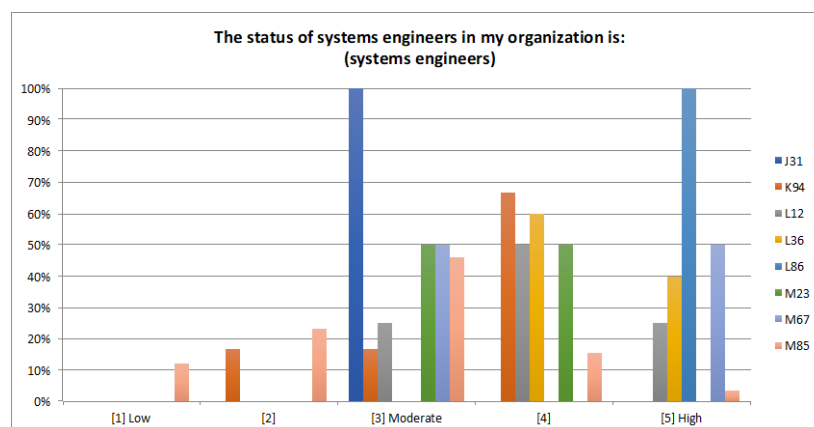


Figure 28. Across-Organization View of Perceived Status of Systems Engineers (by Systems Engineers)

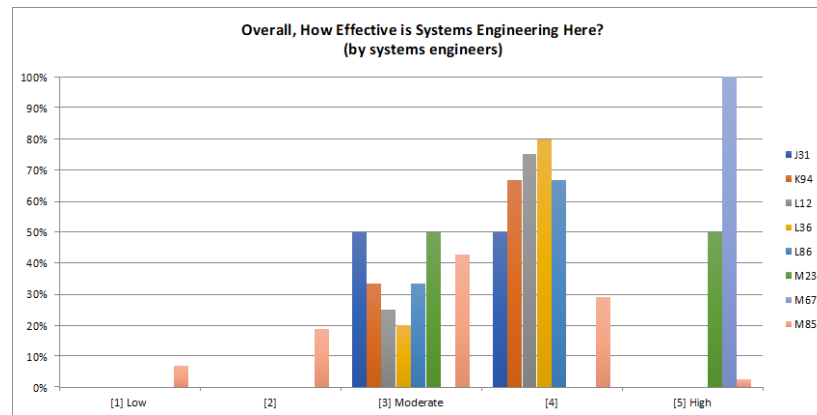


**Figure 29. Across-Organization View of Overall Systems Engineering Effectiveness (by Systems Engineers)**

Figure 29 provides a view of the question on overall effectiveness for systems engineers. Generally, effectiveness is viewed by systems engineers as neutral to positive. It is worth noting that M85 had nearly 100 systems engineers participating, so it is possible that a broader distribution would be seen if larger samples were available.

Examining the free-text responses to place ratings in context, systems engineers report the following reasons for their ratings of low or neutral effectiveness: SE is **misunderstood, underused, understaffed, undervalued, discounted because of schedule and cost; inexperienced staff; not organized; not mandated; no fit for purpose tools**; and policies, procedures, and processes.

Systems engineers who rate the effectiveness of SE in their organizations as **highly effective** report the following reasons for their views: **repeatable** processes; deliver **high-quality complex products** on time and budget; **flexible** use of processes and tools; at the table to **influence decisions**; good practices and tools used **throughout the life-cycle**; and **customer and stakeholder access**.

#### **4.4.3 CROSS-CULTURAL INSIGHTS FROM RESEARCH IN THE NETHERLANDS, THE UNITED KINGDOM, AND THE US**

Overall, within the culture of companies studied in the Netherlands, knowledge is power. There is less stratification by role or hierarchy, and results of this culture include: collaboration with a concern for consensus building; people expect to be challenged directly by anyone in the organization; processes are made to fit the project; people perceive themselves to be a federation of brilliant people who influence each other for the common good; and people respect work-life balance. A common description of the work of a systems architect<sup>1</sup> was, “I talk with people for a living.” The role requires significant relationship building and communication skills. Teams seek out people with SE skills who enjoy and know how to collaborate across roles and disciplines. In several cases, the systems architect was an equal collaborator and decision maker with the project and program managers.

<sup>1</sup> In the Netherlands, the term “systems architect” was consistently used to describe a “systems engineer” as defined in Helix. To reflect the data accurately, “systems architect” is used for findings from the Netherlands.

In Hofstede's research on cultural differences between the Netherlands and the US, managers in the Netherlands: support people; decisions are made by involvement and people value equality, solidarity and quality in their work lives. All of attributes are consistent with a low score on "Masculinity", and illustrate the dominant values of caring for others and quality of life. According to Hofstede, people in the US score higher on Masculinity, and as a result—and in contrast to the Netherlands: people "strive to be the best they can be"; being able to show one's success is a great motivator; Americans "live to work"; and winning matters as evidenced by the conflicts from political polarization and the ubiquity of court cases.

In the US and the UK, the organizations studied showed more concern about making projects fit the process. Power was described as coming from order including role, function, and organization affiliation.

### **Observations about Organization Governance**

Following are observations about organization governance from organizations in the Netherlands:

- Decisions were taken at low levels. Pushing "power to the edges" was a strategy that enabled the experts closest to the technical decisions to manage and own the decisions. As noted below, these decisions were not made in a vacuum as the culture valued discussion and consensus.
- Hierarchy existed on paper, though Systems Architects/Systems Designers (SA/SD) were expected to challenge anyone. People in the hierarchy were likely to defer to the local experts when they made compelling arguments.
- Strong consensus decision processes were used for most decisions. These processes relied on high participation, allowing decisions to emerge from the collective experience of the group. There were few surprise decisions made in private and handed down to the team.
- These high-participation decision processes had several advantages. The high cognitive and experiential diversity brought to bear on decisions by inclusion enabled well thought-out decisions understood and accepted by all.
- Disadvantages of high-participation decision processes included loss of speed and decision instability. Because so many people expect to give input on decisions, conversations extended over time and decisions didn't always stay "final" as conversations continued to include more people. High-participation decision processes were effective in teams where people knew each other well and respected the expertise in the group, but these processes were harder to scale with many new people who had not yet earned social influence credibility. The informality of the decision process could also lead to cognitive decision bias traps when the team is not vigilant to test assumptions and challenge their own perspectives.

Following are observations about organization governance from US organizations:

- The forms of governance in industry and government organizations in the US vary, though decision processes tended to rely more on hierarchical decision making rather than working-level team consensus.
- Often, SA/SD made recommendations to higher-level leaders who then relayed the recommendations to another level of project or program management to make the major decisions. Systems engineers were sometimes called in to explain the recommendations to the senior leaders. Sometimes the hierarchical decision maker was a systems engineer, but often the leader or leaders who made major decisions had broader responsibility.

### **Observations about Organization Structure**

Following are observations about organization structure from organizations in the Netherlands:

- Work was often organized by project, where decisions optimized the functions and performance of the components of that project. Project focus reduced time and attention to platform design and implementation. Though architects saw the need for building robust cross-project platforms, fewer resources were devoted to these components of roadmaps. The project-focused structure supported short-term speed and agility of specific projects, but hampered re-use of components and platforms. Engineers and managers were aware of the tension between project- and platform-focused organization structures and some were experimenting with adding cross-project architects and groups.
- In addition to project accountability, SA/SD had some functional affiliation.
- The terminology referring to systems engineers varied, with systems architect used for SE functions particularly in the broader, earlier phases of projects and the term systems designers used for more detailed component-level design.
- In some places, SA/SD had a lead role and an equal role in project management and decision making with Project Management and Marketing.
- Advantages of project-focused structures included enhanced integration of SA/SD in project decisions, SA/SD development of deep expertise in project-specific architecture and design, and SA/SD integral to the team focused on the business need.
- The challenges project-focused structures faced centered around difficulty of architecting for reuse and platform development and a sense that these platform decisions were not "owned" by SA/SD in the project trenches.

Following are observations about organization structure from US organizations:

- Systems engineers often resided in functional SE organizations and were assigned to projects from that "home base."
- The functional SE organizations had to place SEs on official projects to obtain funding for systems engineers. Not all projects wanted to pay for the optimal amount of SE resource.

- Systems engineers reported that they often had responsibility for technical decisions, but did not always have authority to make them.
- Systems engineers were often evaluated by functional managers, not by project leadership. The advantage of this structure was that systems engineers were being evaluated by people knowledgeable in the discipline who could also provide concrete growth recommendations and resources for that growth. The disadvantages of this structure were that sometimes the SE manager did not have enough visibility into the SEs work to provide accurate or actionable feedback, and at times, the project leaders did not agree with the functional manager about what an individual SE should be doing or how they should be evaluated.

### **Observations about Methods, Tools, and Processes**

Following are observations about methods, tools, and processes from organizations in the Netherlands:

- The drive for flexibility and continuous improvement in the Netherlands companies relates to the observation that there were few common standards for tools, even within companies. The high value expressed for "fit for purpose" tool selection, the desire for flexibility in choosing which SA/SD tools are implemented on a project, and the focus on projects rather than platforms contributed to the diversity of tools used.
- The most common model for systems engineering reported was the V model, while the waterfall model was also used in some places. Some reported discussions and conflicts between hardware and software communities about which SE processes should be used, with software communities advocating for use of more agile methods.
- Engineers and managers reported being aware of and interested in MBSE, though many were skeptical about the feasibility of implementing wide-scale MBSE in the near future.
- As many SA/SDs were deeply embedded in technology specific projects, often without a functional job title specific to systems engineering, few interacted with other SA/SDs in professional organizations to share and learn new tools and practices. Some reported identifying more strongly with their project or company than with their technical discipline.

Following are observations about methods, tools, and processes from US organizations:

- The V model (may be called DoD 5000.2, V model, etc.) was the most common approach used.
- Awareness of the desirability of migrating to Incremental/Spiral development or agile approaches was expressed but not common in practice.
- MBSE/MBE/MOSE/DE were gaining popularity in SE organizations and largely viewed as experimental, not mainstream. Only a few organizations claimed to really know how to utilize these approaches at scale. People did not report

standardization of tools, though in the Helix sample, Doors was the most common requirements tool reported.

### **Underlying Cultural Assumptions about Systems Engineering Effectiveness**

- Some US organizations believed the following defined them as a more “MATURE” SE organization: structured SE processes; extensive tool use; clear career paths; well-supported expertise development; external professional involvement; and explicitly highly valued roles and job titles.
- In general, when someone in the US says something is more “mature,” they mean “better.”
- For European companies or divisions that work with divisions and other companies in the US, cultural beliefs about SE “maturity” can cause negative judgments and get in the way of open collaboration. Innovative and effective work can result from strong codification of SE identity and development or from low codification of SE. Both operating models can generate effective SE capability. Working across cultures, however, brings these underlying assumptions to the surface, making for conflict about how one “should” do the work.

---

## **4.5 SYSTEMS ENGINEERING VALUE**

**How Organizational Characteristics Impact Consistent Delivery of SE Value.** Looking at the six primary values delivered by effective systems engineers (as uncovered in earlier research), several organizational characteristics in the current research were found to impact effectiveness, either positively or negatively (see Table 3).

**Table 3. Primary SE Values and the Ways Organizations Impact SE Effectiveness**

| <b>Six Primary SE Values</b>       | <b>Ways Organizations Have Positive Impacts on Effectiveness</b>            | <b>Ways Organizations Have Negative Impacts on Effectiveness</b>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               |
|------------------------------------|-----------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 1. Keep and maintain system vision | Support customer and stakeholder access through the lifecycle of a project. | <ul style="list-style-type: none"> <li>• Although most organizations believe Model-Based System Engineering (MBSE) is important, many feel MBSE is not well understood within and across functions. Early MBSE implementations have not always demonstrated the full value of the approach, and teams have had difficulty getting buy-in from developers to make full use of the methods.</li> <li>• The “agilization” of software has become an expected and valued approach to software engineering, but now companies struggle to make similar speed and flexibility advances in</li> </ul> |

| Six Primary SE Values                                                           | Ways Organizations Have Positive Impacts on Effectiveness                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 | Ways Organizations Have Negative Impacts on Effectiveness                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            |
|---------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
|                                                                                 |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           | hardware domains. This is seen by many as the next frontier for complex system design and delivery, and people are looking to SE to advance the cause.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               |
| 2. Translate technical jargon into business or operational terms and vice versa |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      |
| 3. Enable diverse teams to successfully develop systems                         | <ul style="list-style-type: none"> <li>• Keep key people in place, and invest in knowledge transfer for people (SEs and others) who must rotate in and out of projects.</li> <li>• Staff teams with cognitively diverse people.</li> <li>• Designing, using, and customizing processes that fit project and stakeholders needs lead to acceptance of SE expertise and increases value.</li> <li>• Support high-value repeatable processes while also seeking and sensibly implementing innovation and flexibility in process and tool choices.</li> <li>• Set an organization-wide standard for behaviors that drive psychological safety.</li> <li>• Ensure aligned role clarity of SEs across the organization.</li> <li>• Effectiveness correlates with people's views about how generative the culture is: curious, encouraging, experimental, forceful, inquiring, and nurturing.</li> <li>• Cultures that value and build individual and group collaboration skills (CVF</li> </ul> | <ul style="list-style-type: none"> <li>• Constant personnel changes undermine efficiency, and the quick succession of leaders undermines mission clarity on projects that require long-term focus.</li> <li>• Conflict occurs when different mindsets simultaneously operate on a project. The military or operations mindset values speed and action and conflicts with the SE mindset that values data-driven decision making, process integrity, and testing.</li> <li>• System complexity requires different skills, tools, and strategic approaches than currently commonly available. These organizations find it difficult to hire systems engineers with cutting-edge knowledge and tool experience, and often don't have the time, money, and expertise to acquire the tools they'll need as systems get more complex and schedules get shorter.</li> <li>• Software has become more central to products of all kinds. Systems engineers, however, often come from hardware backgrounds and do not have the needed software experience or depth of knowledge. Similarly, leaders of SE organizations typically have hardware engineering backgrounds and are seen as not adapting to the changing priorities of software/hardware development.</li> <li>• Though most people view their organizations to be evolving, only those</li> </ul> |

| Six Primary SE Values                                   | Ways Organizations Have Positive Impacts on Effectiveness                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       | Ways Organizations Have Negative Impacts on Effectiveness                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            |
|---------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
|                                                         | Clan Cultures) may be viewed as effective (not enough data).                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    | that see this evolution as being positive (“improving”) believe the SE organization is effective. Cultures viewed as hierarchical, cautious, and conforming are less likely to be viewed as effective.                                                                                                                                                                                                                                                                                                                                                                                                                                                                               |
| 4. Manage emergence in both the project and the system  | Dedicate resources for SE to reach out to other organizations (internal and external) that are advancing the discipline as the field and complexity of projects change.                                                                                                                                                                                                                                                                                                                                                                                                         | <ul style="list-style-type: none"> <li>• Keep projects in tight silos, removing opportunities for cross-project learning, reuse, platform development, systems thinking, and future awareness.</li> <li>• Organizations struggle with finding the balance between investing in platform development and focusing on the immediate and unique needs of individual projects. SE organizations “know” they need better road maps and reuse of designs, but often do not have the organizational backing to invest time and expertise in forward planning and integration.</li> </ul>                                                                                                    |
| 5. Enable good technical decisions at the systems level | <ul style="list-style-type: none"> <li>• Continually push down hierarchy and increase empowerment enabling proficient SEs to own key decisions.</li> <li>• Actively educate technical and managerial communities about the expertise, roles, and value of SEs, which would in turn increase the respect of, reliance on, and accountability by SEs.</li> <li>• Include proficient SEs in decision forums across the life cycle of projects and in the development of cross-project platforms and roadmaps.</li> <li>• Use SE skills in making data-driven decisions.</li> </ul> | <ul style="list-style-type: none"> <li>• Schedule focus can override using important SE processes limiting SE contributions and jeopardizing quality.</li> <li>• In the government organizations studied, systems engineers did not feel respected, valued, understood, or championed.</li> <li>• Given the common practice of government projects using contract organizations for critical products components, they sometimes struggle to maintain internal SE skills when most of the SE work is being done by contractors. SE excellence is necessary in government organizations to ensure systems-of-systems integrity and provide direction for the contract SEs.</li> </ul> |

| Six Primary SE Values                    | Ways Organizations Have Positive Impacts on Effectiveness                                                                                                                                                                                                                                                                                                                                       | Ways Organizations Have Negative Impacts on Effectiveness |
|------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------------------------------------------|
| 6. Support the business case for systems | <ul style="list-style-type: none"> <li>• Listen to SEs when making major tradeoffs among cost, schedule, quality, customer requirements, system reliability, manufacturability, test, repair, etc.</li> <li>• Cultures that look outward (CVF external focus and differentiation) combine product vision with customer focus and seek innovative ways to find and use new resources.</li> </ul> |                                                           |

**Extending the Concept of “Value” from Individual SE Capabilities to Organization Capabilities.** Table 3 above shows how the organization leadership and collective organization culture affect the ability of individual systems engineers to deliver consistent value. The Helix team sought to explore whether there are specific values that the leaders must deliver for all systems engineers to deliver the benefits of their expertise and roles.

Identified beneficial values included:

- Motivate and retain excellent cognitively diverse systems engineers.
- Educate engineering community about value, expectations, processes, tools, and decision authority of systems engineers.
- Co-create governance structures and norms that maximize use of SE expertise, judgment, and SE data across the lifecycle of projects and platforms.
- Design and support forums for continuous learning and cross-project, cross company connections.

---

#### 4.6 SYSTEMS ENGINEERING ANALYZER DASHBOARD

The interview transcripts and survey responses gathered by the Helix team contained qualitative text-based data as well as quantitative data. The Systems Engineering Analyzer Dashboard was developed with the purpose of using these datasets to generate analytical visualizations with the prospect of extracting meaningful insights from these datasets. The data was analyzed using text analysis, text mining, and sentiment analysis approaches. The goal of the tool was to aid a better understanding of the roles of systems engineers, find connections between SE and organizational culture within the SE workforce, compare SE lifecycle activities and concerns across multiple settings, and enable SE organizations to assess the effectiveness of their SE workforce and SE capability.

Data pre-processing and cleaning, as well as categorizing, were important steps in text analysis to extract meaningful insights and draw conclusions from the datasets. Along the aggregated interview data and survey responses, the team also collected open source literature related to the SE domain knowledge and related fields to complement the datasets. The literature data is referred to as the SE knowledge repository documents. Figure 30 represents the framework the text analyzer dashboard used to extract insights from the data.

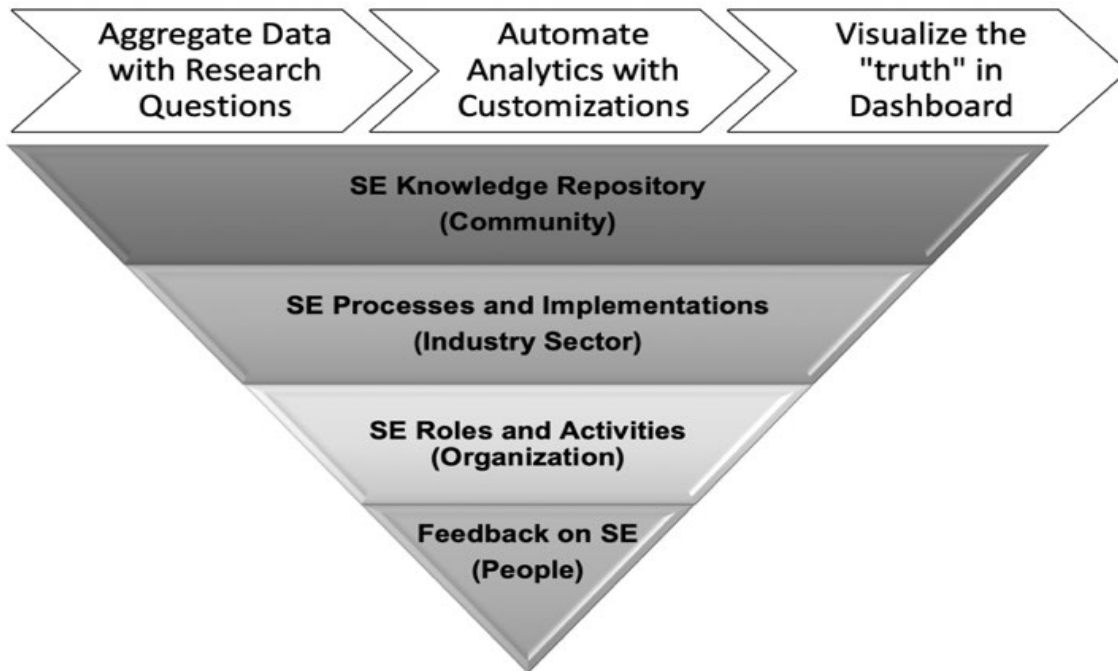


Figure 30. SE Analyzer Dashboard Framework

The interview transcripts had raw textual information that needed to be cleaned before performing any text analytics. The team performed data pre-processing steps such as tokenization, removal of stop word, and lemmatization to clean the raw textual information within the interview transcripts before performing text analytics. To capture contextual relationships among phrases and words, and to detect relevant concepts and phrases, the SE knowledge repository was used to train word embeddings with a Word2Vec model. For example, the trained word embeddings would indicate that the phrase 'defense system' is closely related to 'large delays'.

The SE Analyzer Dashboard was organized into the following four levels, as illustrated in Figure 30:

1. **Community Level:** SE knowledge repository was used to derive relationships between SE and the factors that contribute to the effectiveness of SE capability, such as organizational culture, system processes, people, and teaming. Figure 31 shows the first tab of the dashboard that has several word cloud snapshots of the SE knowledge repository. The first word cloud shown is about the SE domain knowledge. Phrases such as risk management, stakeholder requirements, validation

process, and integrated life cycles were the concepts that were automatically extracted from the dataset.

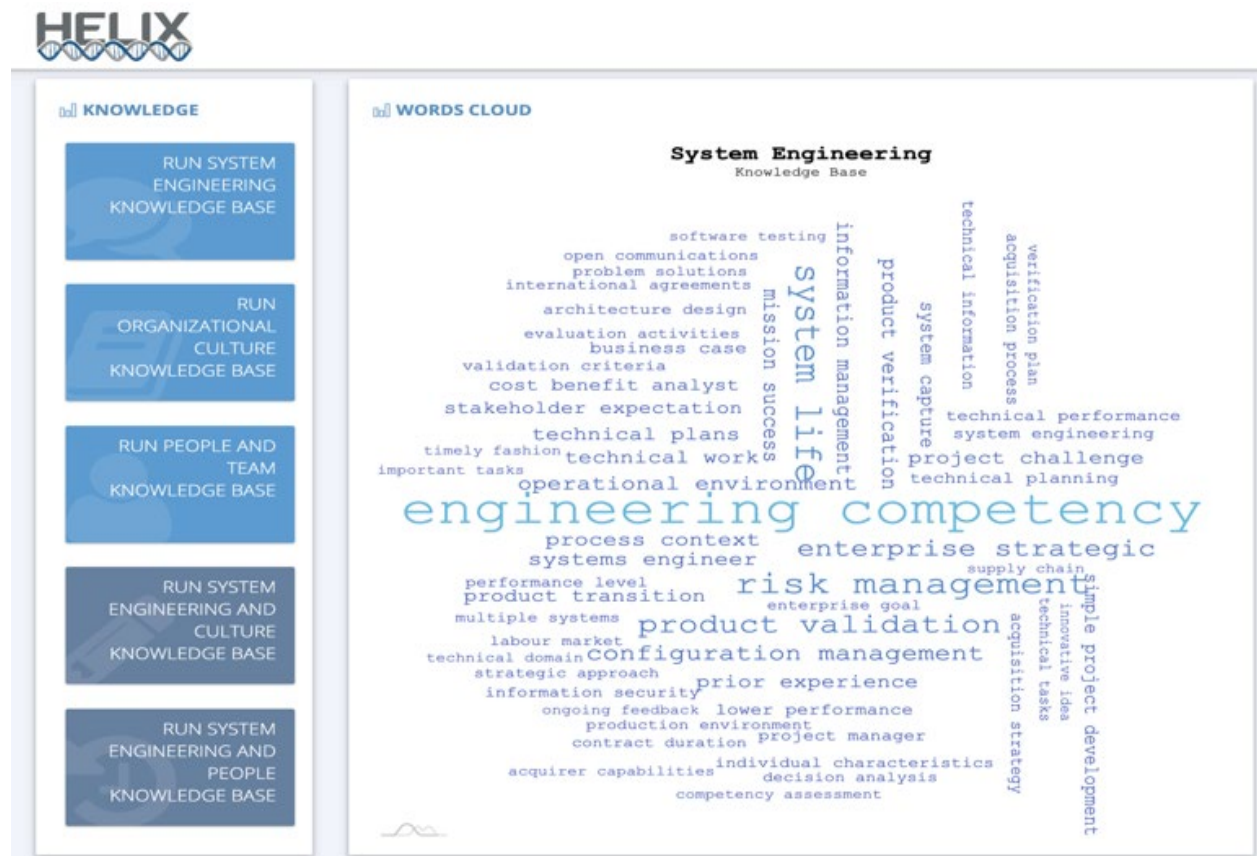


**Figure 31. SE Knowledge Repository Tab in the SE Analyzer Dashboard**

Based on the intersection of SE with the literature regarding managing people and customer relations in the organization, phrases like problem solving, project management, team performance, evaluation criteria, decision making process, and customer satisfaction emerged. With the knowledge repository intersection capability, the connections were formed and viewed between SE and the related disciplines. This enabled the dashboard user to see if the topics that subject domain experts raised and emphasized in the Helix interviews appeared.

2. **Industry Level:** Defined how SE activities, processes, and contributions were described in the Helix interviews, and compared them across domains such as defense systems, commercial aerospace, healthcare, transportation, and others. This helped researchers and SE practitioners to understand the differences of SE realization among industries. Figure 32 shows the second tab in the dashboard that compared how SE topics appeared in the Helix interview transcripts across domains that focused on complex technological advancements, information technology, and transportation. Figure 32 indicates the interviewees from the defense and transportation sectors placed an emphasis on System Implementation and Development, while the information technology sector shared more about their people and team.



## Helix Evaluation

Home &gt; Organization

## SYSTEM ENGINEERING ANALYSIS

Basic Synonyms Similarity

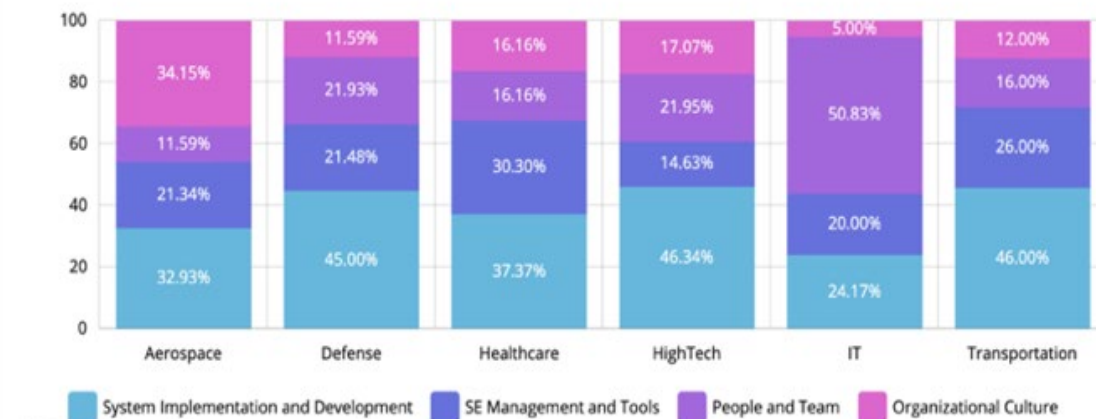


Figure 32. Industry Tab in the SE Analyzer Dashboard

The section shown in Figure 33 could be accessed by scrolling down in the organization tab. It provided a detailed breakdown of the information regarding each topic and the phrases detected in the Helix interview transcripts that are relevant to each topic. The heat map shows the normalized phrase frequency for each phrase in each domain. For example, under the SE tools dropdown menu, risk analysis was one of the focus areas, and risk management, risk reduction, and risk identification were the phrases that were identified in the risk analysis tool. The heat map shows a transformed index for each phrase and the respective domains. The darker the color, the higher the normalized phrase frequency appeared, and vice versa. The user could see from the information technology domain interviews that risk was not mentioned. On the other hand, it seemed that the defense industry used phrases such as program risk, and risk management more frequently.

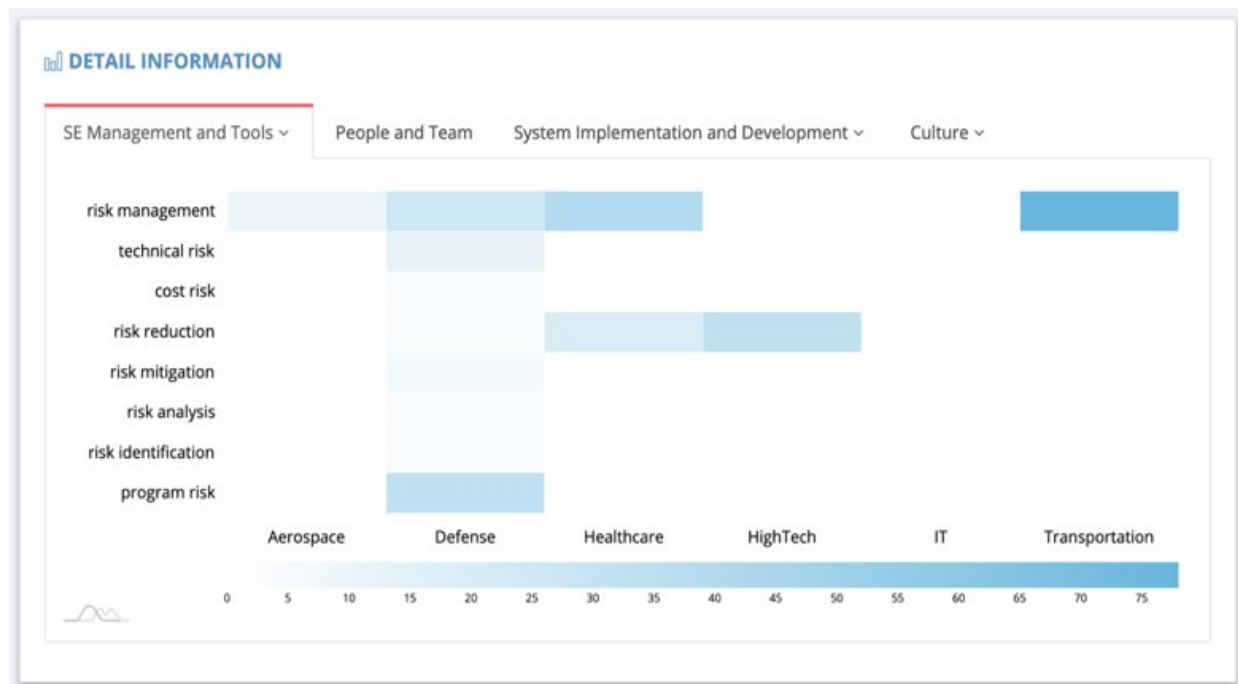


Figure 33. Industry Tab in the SE Analyzer Dashboard (Continued)

3. **Organization Level:** To derive an organizational profile on SE, the Helix team combined the quantitative survey data with the interview data. The dashboard shows how participating employees from an individual organization addressed a group of detailed questions, so the organization could learn employees' perspectives, and leaders of the organization could reflect on what and how to improve SE effectiveness on a predefined list of survey questions, as shown in Figure 34. Each bar in Figure 34 represents a survey question, with an auto-detected most-relevant sentence extracted from sample answers, the average score to the question, and an abbreviation of the question name on the left of the bar. The colored bar shows the overall score distribution. For example, COLLABORATE indicated that if there are collaborations with systems engineers on your project, it has an average score of 4.25. More than 80% of the interviewees were quite positive about collaboration, with one of the detailed answers being "Everyone is open for collaboration."

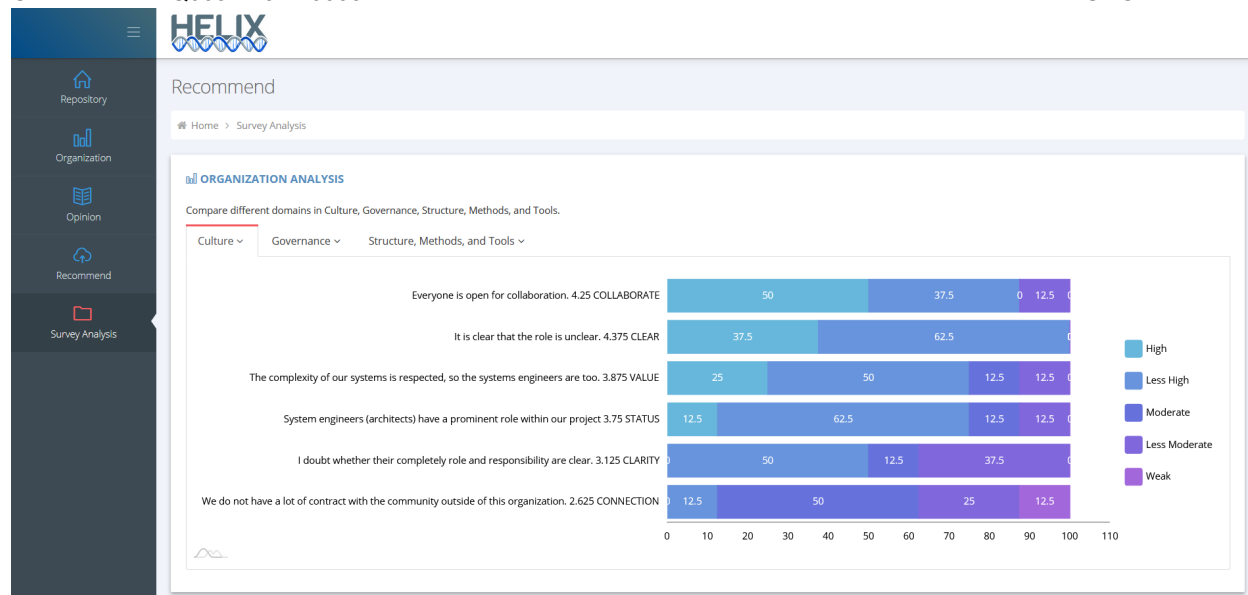


**Figure 34. Organizational Survey Data Analysis Tab in the SE Analyzer Dashboard**

Figure 35 illustrates how answers to individual questions varied from organization to organization. These visualizations enabled organizations to learn from their peers and motivate or support future improvement efforts. The pie chart in Figure 35 shows the percentage of level 5 answers (Strongly Agree) among organizations, with a text summary automatically generated for each question. Users could view how percentages changed according to level.

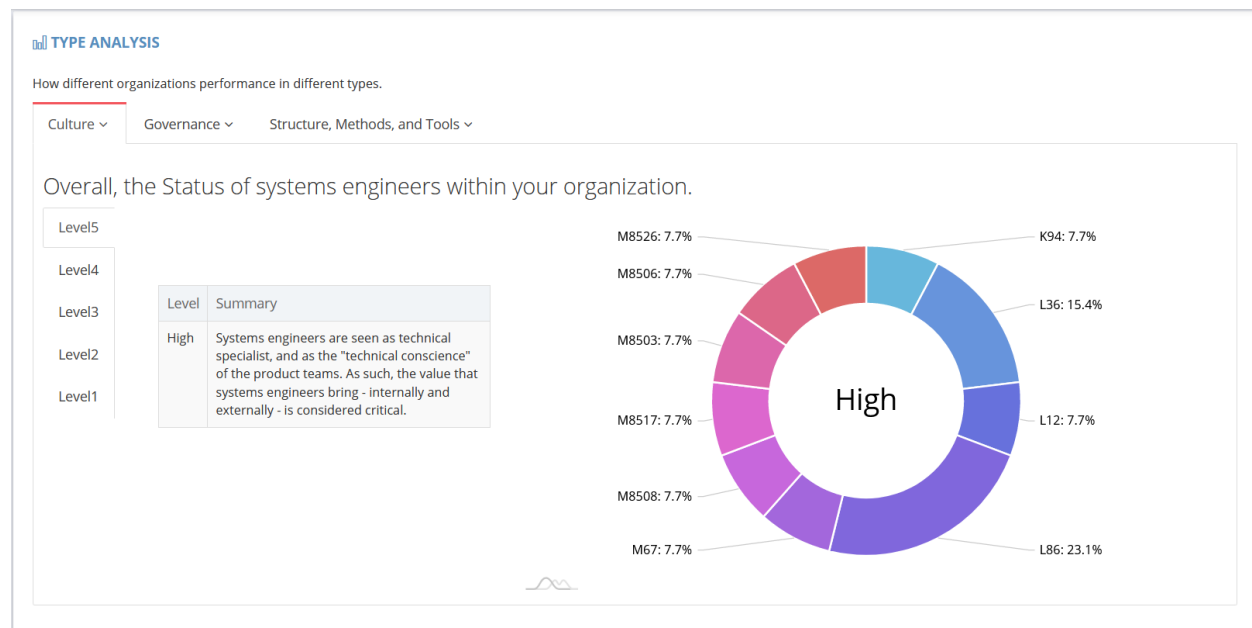


**Figure 35. Example of Organizational Culture Survey Data Analysis Tab in the SE Analyzer Dashboard**

- 4. People Level:** This level identified major concerns and accomplishments from individual systems engineers and senior leadership from the Helix interview transcripts. Gathering opinions about SE tools and activities could help users to explore additional or detailed factors that could contribute to the effectiveness of an

SE workforce and summarize lessons learned from the survey responses. In the opinion tab (see Figure 36), the Helix team automated the process of determining whether interviewees' subjective opinions about SE tools and activities are positive, negative, or neutral by using sentiment analysis. The team adopted an iterative semi-supervised sentiment analysis approach, combined with human expertise to create a high level of accuracy in coding interviews. The team first identified and filtered sentences with interviewees' subjective opinions and attitudes, and cross tagged them with concepts and topics. Then, the team re-defined commonly used sentiment libraries and made them more suitable for interview data. The team manually validated tagged sentences and used them as training sets for deep learning to detect similar sentences with polarity.



**Figure 36. Opinion Tab in the SE Analyzer Dashboard**

For example, one interviewee found mentoring and training activities such as “executive leadership development program” to be “incredibly valuable”, while another interviewee found that “reliability analysis” as a SE tool to be “interesting”. Another interviewee found their specific “analysis program” work very dull and mentioned further, “wasn’t applying any systems engineering experience to it.” Gathering enough opinions about SE tools and activities could enable users to define how effective the SE workforce is in each organization, and how to improve the SE effectiveness in the long run.

Overall, the SE analyzer dashboard was a good initial experimental research effort. This dashboard was one of the ways the Helix team tried to visualize all the open-source SE-related literature, Helix surveys, and interview data. If time permitted, the team would have performed more in-depth analysis using this dashboard and obtained better results. This dashboard could be useful for data visualization if researchers had more time and resources, as well as a larger dataset to analyze.

## 4.7 ATLAS UPDATE

While the focus of *Atlas* is around systems engineering, it is important to have a framework for what effectiveness means in general. A generic definition of effectiveness is “the degree to which something is successful at producing the desired result.” At the highest level, *Atlas* is about individuals and organizations. The different facets of an individual are innumerable, but in the context of effectiveness at work, their skillsets and the job they are expected to do are critical. It’s also critical that an individual’s job be aligned with their skillsets and vice versa. This does not mean individuals should not seek jobs that challenge them and allow them to build new skills; rather, a major misalignment between skills and jobs will hinder the ability of individuals to consistently deliver critical values, thus limiting effectiveness.

Individuals work in the context of organizations. An organization has a specific culture that is reflected in its leadership, governance, and policies. When these are aligned with the culture, it is easier for organizations to be effective; a misalignment can, again, inhibit effectiveness. Leaders identify critical values that individuals and the organization as a whole are expected to provide, and those values should be supported by governance approaches and policies. Organizations also assign individuals to their jobs; if there is a strong misalignment between an individual’s job and skills, this may also be a reflection of a misalignment between an organization’s culture and espoused critical values.

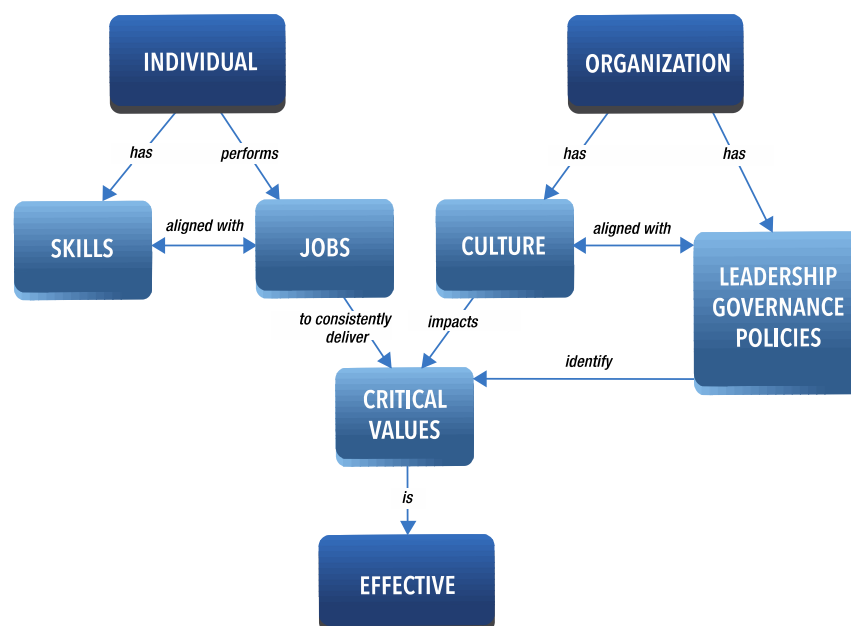


Figure 37. Generalized overview of Organizational Effectiveness

The key takeaway from the overview in Figure 37 above is that an organizations sets the expectations for what the desired end results (critical values) are in a work environment. When an organization's culture is in tension with the policies and approaches intended to bring about those values, it is harder to be effective. Likewise, individuals need to be in a job that takes advantage of their skillsets in a way that allows them to deliver the critical values sought by the organization. Alignment and balance of these different parts is critical.

Figure 37 provides the context of discussion around effectiveness. Figure 38 and Figure 39, following, provide the lens of what it means for an individual or an organization to be effective within the context of systems engineering. As with the overview of effectiveness in Figure 37, the next level of detail down, i.e., the specifics around the different parts of each diagram, delve more into detail around systems engineering.

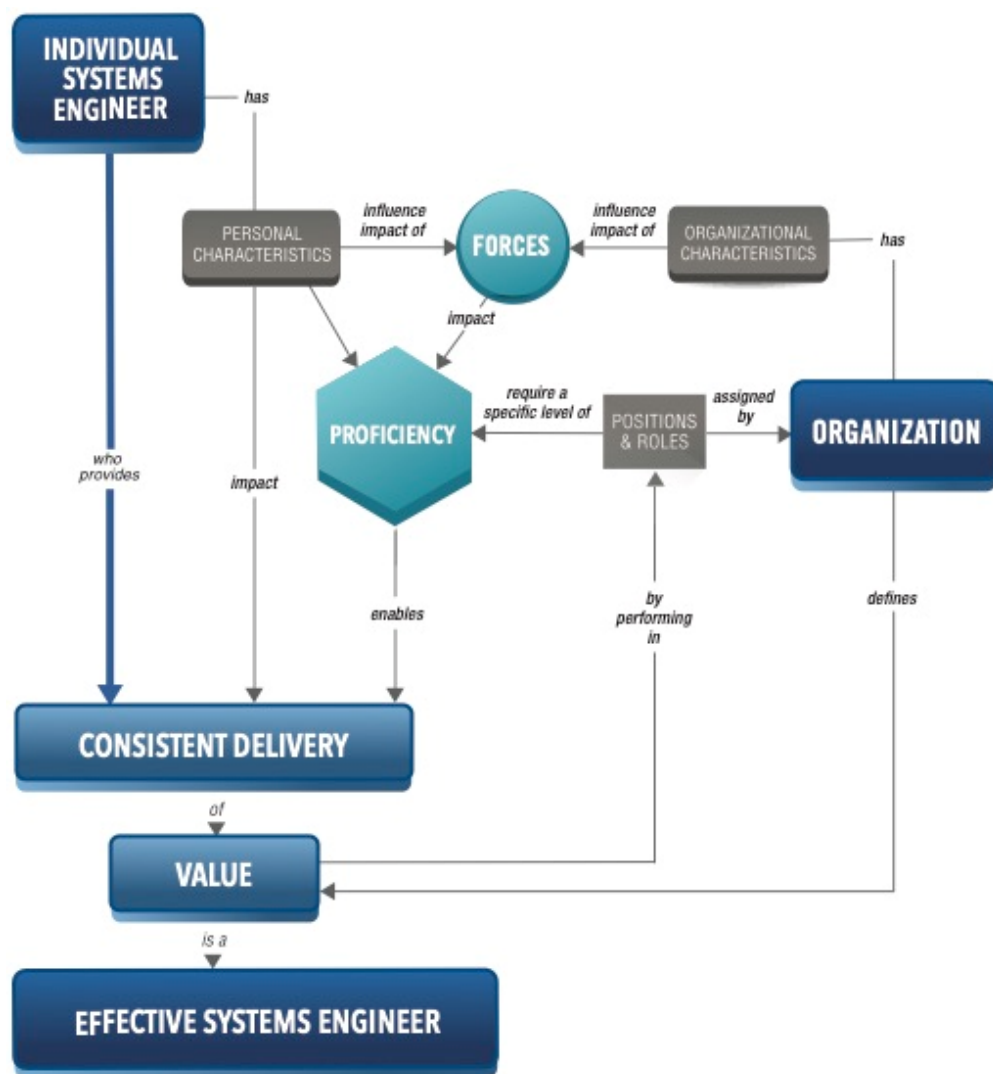


Figure 38. Atlas

The main theme of *Atlas* for individuals is that an 'Individual Systems Engineer who provides Consistent Delivery of Value is an Effective Systems Engineer'. This fundamental definition of an effective systems engineer hinges on value, and it can be seen that an organization defines value. Therefore, it is on the organization to define the value that the systems engineer is

expected to provide. Further, the individual systems engineer provides value by performing in positions and roles assigned by the organization. Therefore, it is again on the organization to establish the position of the systems engineer in terms of roles and responsibilities, keeping in mind that positions and roles require a specific level of proficiency that enables consistent delivery of value.

The core of *Atlas* is the proficiency of the individual systems engineer – what proficiency means, and how it can be improved. An individual systems Engineer personal characteristics that influence the impact of force' and each organization has organizational characteristics that influence the impact of forces – each of which may have a positive or a negative influence. Further, both personal enabling characteristics and organizational characteristics impact consistent delivery of value; again, the impact can be positive or negative. Amidst all these influences and impacts, the challenge for the individual systems engineer and the organization is to improve the 'proficiency that enables consistent delivery of value to the organization.

The color-coding of the diagram in Figure 5 is designed to show the relationships between various elements of *Atlas* as follows:

- Dark blue: Primary actors (individual systems engineer and organization) that enable or inhibit effective systems engineers.
- Teal: Elements related to the skills of systems engineers, i.e., the specific skills themselves or how they are developed.
- Grey: Characteristics of the primary actors, including: characteristics of individuals and organizations; the roles and positions of systems engineers defined by organizations; and the initiatives taken by individuals and organizations to improve a effectiveness.

The *Atlas* overview illustrated in Figure 5 can be assessed as a snapshot in time, but many of the elements of *Atlas* are dynamic in nature. The level of proficiency of an individual systems engineer is not fixed; rather, it is constantly changing due to the impact of forces over time. Similarly, other elements of *Atlas*, including characteristics of the individual systems engineer and of the organization, continue to change over time. Further, as the level of proficiency of an individual systems engineer increases over time, the organization is likely to place that systems engineer into different positions and roles.

This dynamic aspect of *Atlas* is not captured in the overview, but is reflected in individual career paths over time: the precise combination and characterization of the forces they experience over their entire career. An example of a career path map is seen in Figure 6. See Section 6.4 for additional discussion of career paths.

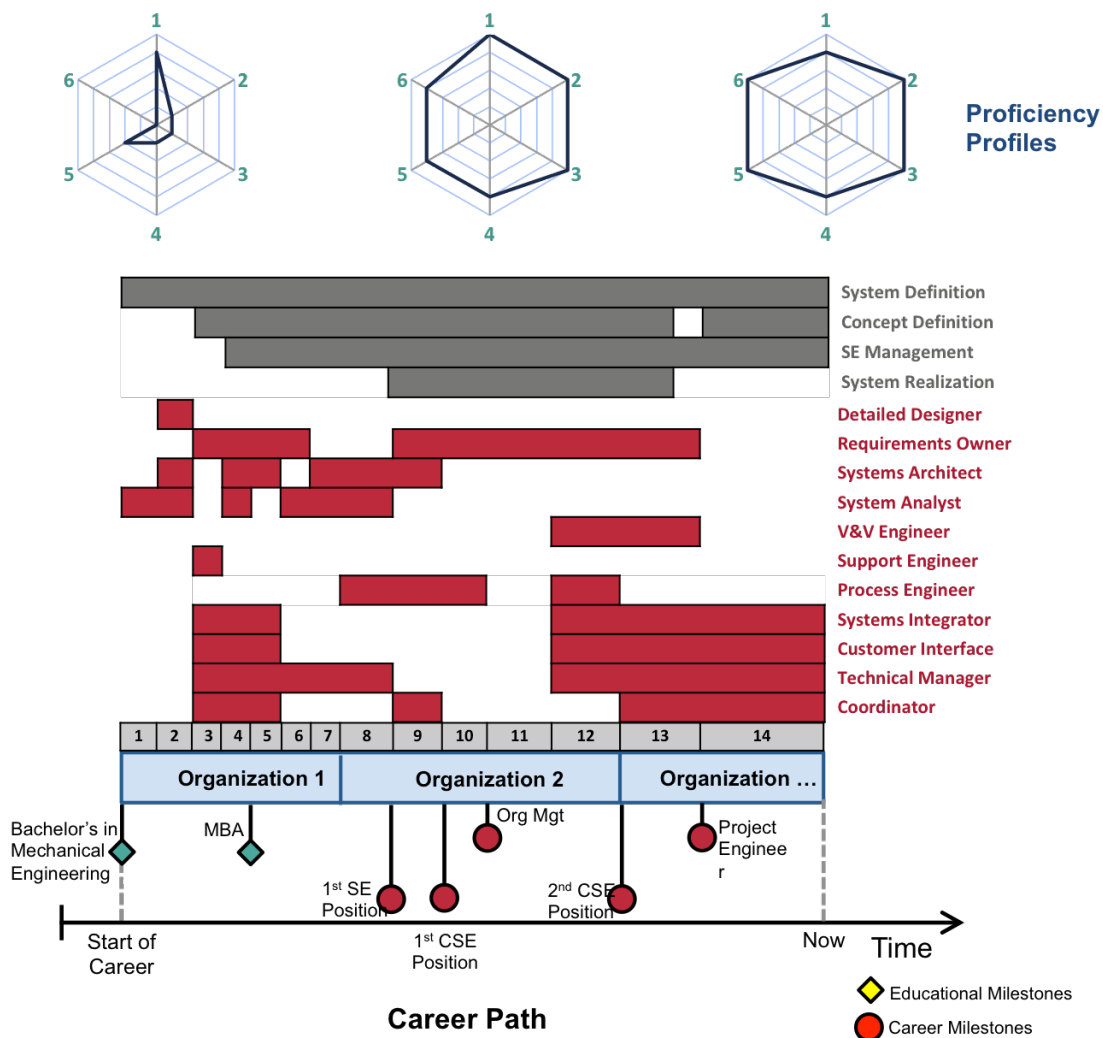


Figure 39. Career Path: A Dynamic View of *Atlas*

The Helix team defined methods to depict and analyze the career paths of systems engineers. The team also used those methods to analyze the systems engineers in its interview sample and to understand how those systems engineers are shaped by the impact of forces, positions, and roles over time. These are reflected in the companion *Atlas Career Path Guidebook*.

#### 4.8 SYSTEMS ENGINEERING CAPABILITY

The term capability is commonly used in operational and acquisition contexts within the defense community. In a broader context, capability is “the ability to achieve a desired effect under specified (performance) standards and conditions through combinations of ways and means (activities and resources) to perform a set of activities” (DoD, 2009). Capability engineering can therefore be defined as the “overarching approach that links values, purpose, and solution of a systems problem” (Henshaw et al., 2014). Using a soft systems methodological approach, the INCOSE UK working group identified eight perspectives of capability and capability engineering (Henshaw et al., 2014). In the 2018 INCOSE Systems Engineering Competency Framework, one of the new framework competency areas included capability engineering as one of the core SE principles (INCOSE, 2018).

Based on the adaptation of various literature definitions of capability, SE capability is defined in terms of people (competencies), processes, and equipment, the integration of which leads towards the ability to perform SE activities to produce an engineered product or service. It is worth noting that “competence” differs from “capability”. Capability is an organizational or organizational team attribute that refers to the ability to execute the mission of the organization (INCOSE, 2018). The Helix team conducted a literature review of SE capability and built on this work to develop clear methods for understanding and assessing how systems engineers are supported or impeded in providing an effective SE capability.

In all the interviews, the Helix team probed the concept of value. There are two general forms of value from the interview discussions: 1. an individual’s perspective on the primary value that they provide as a systems engineer; and 2. an individual’s perspective of the overarching value that the community of systems engineers in their organization provides. Most systems engineers defined value in terms of the overall project success with respect to the “iron triangle”, which is a well-known metaphor based on the fact that the three dimensions of a project compels its success. Although there are numerous adaptations of the “iron triangle”, two corners of the triangle are *time* and *cost* (or synonyms for those terms). The third corner may vary but is usually *requirements, scope, quality, or capability* (Pyster et al., 2018).

The Systems Engineering Book of Knowledge (SEBoK) has identified the need for determining the required SE capabilities in businesses and enterprises (BKCASE Editorial Board, 2017). The SE capabilities support the SE organizational strategy and the following are essential steps that can help an organization determine its desired SE capabilities (BKCASE Editorial Board, 2017):

- Understand the context.
- Determine the required SE roles.
- Determine the competencies and capabilities needed for each SE role.
- Assess the ability and availability of the needed SE organizations, teams, and individuals.
- Make adjustments to the required SE roles based on ability and availability.
- Organize the SE function to facilitate communication, coordination, and performance.

In 2008, Andres and Peterson presented on SE capability development and highlighted the notion that increased complexity in systems demands increased SE capability. Traditional SE approaches are insufficient for the growing large-scale, complex systems. Key considerations for increased SE capabilities are as follows (Andres and Peterson, 2008):

- Agile and lean processes for rapid development.
- Integration of advanced technologies across multiple systems of systems.
- Increased demands requiring optimal trades or balancing.
- System of systems analysis and interoperability among these systems.

One important step to success is for an organization to benchmark its own SE capability, identify gaps, and plan for improvements (Andres and Peterson, 2008). The following strategies are outlined by Andres and Peterson to build SE capability:

- Define and document the requirements
  - Conduct quality function deployment (QFD) sessions to gather the voice of the customers (VOC)
  - Benchmark other SE organizations or efforts
  - Leverage DoD, industry or academia research studies
- Baseline capabilities
  - Establish a baseline of SE capabilities and performance
  - Identify areas for improvement and make the business case for proposed changes based on the possible risks and opportunities
- Develop a capability development plan
  - Build a focused and prioritized work plan to address the gaps identified within the organization
  - Leverage strengths and best practices from industry
  - Institutionalize systems engineering

## 5 DISCUSSION

---

### 5.1 CAVEATS FOR INTERPRETING THE DATA

Only a small number of organizations completed both the survey and the interviews, which makes it difficult to test whether the two methods yield completely comparable data, redundant data, or inconsistent data. The advantages of the survey include the ability to use repeatable measures that are easy to score and compare over time as well as provide anonymity to participants giving feedback to organization leaders. The advantages of the interviews include the ability to probe topics of specific interest to people, especially topics that emerge from spontaneous interaction, and the ability to foster comfort discussing the topics that need to be discussed more broadly.

Since the sample size for the survey was small, comparisons of the two different culture measures, CVF and the Qi Index, do not show either consistencies or inconsistencies. Conclusions about which CVF patterns are associated with the most effective SE organization from these data is not possible. Similarly, the data do not show statistically that an organization that scores itself higher on the Adhocracy innovative behaviors and mindsets in the CVF also scores itself highly on the generative behaviors measured by the Qi Index. Using either or both culture assessment instruments in an organization can be a launch-point for organizational conversations about values, behaviors, and ways of operating that help or hinder the success of systems engineering in that organization.

Either inventory can drive positive change. Using both broadens thinking and vocabulary for discussing results in the organization. Obtaining repeatable statistical data also enables benchmarking. By using an external organization like Human Insight to conduct and report the data, organizations can acquire benchmarking data within their industry and beyond.

### 5.2 INSIGHTS ABOUT CONDUCTING THIS KIND OF RESEARCH

People in organizations are eager to discuss what it is like to work there and how their area of expertise is valued within the culture. Giving people opportunities for individual and group reflection about the current state of an organization and about their contributions to the mission of the organization is valued.

The Helix survey took 45-90 minutes to complete online. Several respondents failed to complete the survey. In the effort to explore many topics and to test multiple approaches to obtaining the information (i.e., using two different culture inventories and multiple text box long-answer questions), the Helix survey was too long. This was understood from the survey pretest, but the team chose not to significantly reduce the time required. Future organizations should be more selective and use the Helix questions as a super-set from which to choose. Researchers who are extending this research could consider using more than one survey, each shorter, if they wish to study this range of topics.

There are multiple sources of culture data available beyond the survey and interview methods used in the research, such as:

- Site visits that enable observation of the design and use of space, both of which indicate the extent of easy interaction within and across disciplines.
- Observation of artifacts in hallways and conference rooms such as notices about classes or posters about values, all of which can reinforce or challenge what is said in interviews or culture survey data.
- Many organizations have external presences that project the organizational culture—either the actual culture as experienced by the employees or the aspirational culture used to influence customers and stakeholders. The Helix team performed website analyses for a few companies to determine if the external portrayal of a company was consistent with survey and interview portrayals. For example, looking at the external portrayals of Organization A, as shown in Table 4, the external focus on innovation matched the data captured in the CVF survey questions described in the research findings above. The descriptions of the culture from people inside the company matched the ways they talked about the company in public representations. Similarly, in Organization C, as shown in Table 5, the external representations matched the emphasis on clan and market characteristics reported in the CVF data. This type of analysis can also be a “conversation opener” when performed by people in the organization and compared with survey or interview data.

Table 4. Representation of the Culture in Organization A

| Organization A Culture as described online                                                                                                                                                                                                                                                                                                                                                                                       |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     |
|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <b>Clan (Collaborate)</b> <ul style="list-style-type: none"> <li>• We believe in openness, trust, and togetherness.</li> <li>• We empower talent.</li> <li>• We are passionate.</li> <li>• We value you as a person and professional.</li> <li>• Here, you can be your best self.</li> <li>• Create extraordinary multi-disciplinary and cross-cultural teams.</li> <li>• Everyone contributes to writing the future.</li> </ul> | <b>Adhocracy (Create)</b> <ul style="list-style-type: none"> <li>• We innovate for a living.</li> <li>• We are constantly challenging ourselves to spark creativity and discovery.</li> <li>• We are creating products and applications the world has never seen before.</li> <li>• Our mission is to accelerate new digital X technologies and transform them into local products and services.</li> <li>• We are never satisfied with doing things “the way they’ve always been done.”</li> </ul> |
| <b>Hierarchy (Control)</b> <ul style="list-style-type: none"> <li>• Corporate web page information aligns with current and future desire to be a strong Adhocracy culture.</li> <li>• CVF: Hierarchy, process, and control do not appear in their mission.</li> <li>• Qi Index: Strong empowerment and generative collaboration appear in mission.</li> </ul>                                                                    | <b>Market (Compete)</b> <ul style="list-style-type: none"> <li>• We are global leaders in technology X, Y, and Z.</li> <li>• Our business-to-business products are flagships in the “parent company” portfolio.</li> </ul>                                                                                                                                                                                                                                                                          |

Table 5. Representation of the Culture in Organization C

| Organization C Culture as described online                                                                                                                                                                                                                                       |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           |
|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Clan (Collaborate) <ul style="list-style-type: none"> <li>We are committed to offering an inclusive workplace that is engaging, helps you personally develop, sets you up for success as you mentor, and grows teams and capabilities.</li> </ul>                                | Adhocracy (Create) <ul style="list-style-type: none"> <li><u>XX without bounds.</u></li> </ul>                                                                                                                                                                                                                                                                                                                                                                                                                                            |
| Hierarchy (Control) <ul style="list-style-type: none"> <li>Corporate web page information focuses more on Clan and Market characteristics, similar to the current view reflected in the CVF.*</li> <li>Collaboration is valued within the company and with partners.*</li> </ul> | Market (Compete) <ul style="list-style-type: none"> <li>Market message: Innovation. Transformation. Collaboration.</li> <li>A relentless pursuit to make life better.</li> <li>True partnership means rolling up our sleeves and working side-by-side with our customers... together we tackle the toughest challenges. Our alliances focus on implementing meaningful innovations, centered on xx and yy, designed to break down barriers and complexity, and <u>offer better value</u> to xx, yy, and the overall xx system.</li> </ul> |

\* Nothing directly related to hierarchy came from the online assessment; these notes were taken from the interviews.

---

### 5.3 INSIGHTS FROM RELATED SOURCES AND SCHOLARS

This section integrates social science work on culture with the experience of DoD experts and the Helix data.

---

#### 5.3.1 CULTURE CHANGE EFFORTS AT THE DOD

The purpose of this section of the report is to highlight some efforts at the DoD that are attempting to change the culture of technology innovation, which can accelerate the mindset and behavior changes needed within the DoD systems engineering community. Although Helix has not interacted with the organizations described below, these bright spots can be used by leaders of any DoD technology organization to encourage their organizations to experiment. Also, the culture assessment tools Helix has piloted can be used by any of these (and other) innovation units to capture what makes them successful. Transferring what is learned about increasing SE effectiveness through culture design should be a goal of all members of the community.

As Ash Carter, former US Secretary of Defense describes in his chapter, “Maintaining America’s High-Tech Edge” (Carter, 2019: 320), “America’s technology superiority is not a birthright. It must be earned again and again in today’s rapidly changing and fiercely competitive world.” He goes on to describe that although the DoD is a major funder of research, privately funded commercial businesses and research labs are accelerating the global pace of innovation and making key technologies available to allies and adversaries alike.

Carter identifies gaps in technology needs that funding is not addressing adequately, and three causes of those gaps that involve organization culture generally, and systems engineering specifically. The first cause of the gaps is a cultural belief that funding should “focus on meeting specific requirements defined by the warfighters in the services” (Carter, 2019: 323). This leads to underfunding of new, breakthrough concepts and technologies not already envisioned by people in the field. Second, the painstakingly slow Cold-War approach to requirements definition results in years, if not decades before new systems can be deployed. And third, Carter recognized that “a dangerous gulf had emerged between the Pentagon’s in-house innovation culture and the commercial, global world of tech” (Carter, 2019: 324).

The first two gaps are partly due to disconnects between people doing breakthrough technology research and the warriors who have immediate problems to be solved. In innovation speak, this “valley of death” between technology research breakthroughs managed through DARPA and the adoption of those technologies by the services is the same gap as between R&D and production that is faced by most tech companies. In the DoD case, Congress has recently increased the gap between R&D and production by moving each into distinct, separate organizations and making the need for cross-boundary, cross-cultural communication more important and more difficult (Carter, 2019: 325).

One method for ensuring that new technologies get matched quickly to real and present problems experienced in the field is to create teams whose job it is to accelerate tech transfer. The Strategic Capabilities Office (SCO) created in 2012 was an experiment in agile innovation and deployment. Carter describes several successes in which the SCO brought near-immediate upgrades to existing weapons using either new technologies or new off-the-shelf capabilities previously unconnected to the specific problems faced in COCOM war plans (Carter, 2019: 325-326). The SCO is an experiment in culture change that should be studied: to accomplish its mission, in what ways did SE mindsets, processes, tools, and people change? In what ways did interacting with people from SCO change mindsets and behavior (culture) of people in the services and DoD leadership?

Carter’s third cause of critical technology gaps is remaining too insular: expecting to rely on what is invented within the DoD rather than learning from, building on, and rapidly taking advantage of innovation in the US commercial technology community. Carter’s Defense Innovation Unit (DIU), initiated in 2015, accelerated deals with tech companies and solicited proposals for funding in an array of cutting-edge technology areas. By 2018, the DIU had established “outposts” in Silicon Valley, Boston, and Austin. Although the DIU initially went about the partnership by trying to teach the techies how to do things the government way, which of course was not the purpose, they reversed that

approach to instead learn all they could from the success of engineering in commercial companies (Carter, 2019: 328).

Significant differences in perspectives and culture emerged through the DIU work. Carter observed that civilian tech companies, particularly in the digital technology sector, grew out of the counterculture and libertarian movements in the US, which emphasize independence and distrust of government. This is very different from companies with roots in World War II technology culture, which because of the focus on making nuclear technologies safe for humanity, included a strong sense of public responsibility. Earlier leaders saw defense of the nation as an integral part of their corporate missions. Today, with the globalization of corporate missions, it is less common for technology leaders to view their organizations as dedicated to defending the interests of the US (Carter, 2019: 330). These macro-level differences in corporate and defense perspectives and attitudes make it difficult for the DoD to access and apply new technologies.

To bridge this gap, Carter used a standard change tool: he created the Defense Innovation Board (DIB), which brought together thought leaders from the most successful tech companies and outstanding senior leaders from the services to build understanding and respect for each other's missions. Social psychologists advocate acknowledging differences and testing assumptions to create the motivation to find common goals and seek meaningful opportunities for collaboration later (Ernst and Chrobot-Mason, 2011). Carter asked senior leaders from companies like Google, Amazon, and LinkedIn to spend time in the Pentagon, on ships, at airfields, and with special forces everywhere from Nevada to the Middle East. He promised, "Get to know us. In return, we'll be respectful of your culture, too" (Carter, 2019: 330).

The DoD went further to establish collaboration and mindset changes by creating ways for tech people to complete stints in the DoD and government people to complete stints in tech companies. The Defense Digital Services (DDS) effort, which brings brilliant cybersecurity experts into the Pentagon for a few months to take on top-secret initiatives, succeeded in part because the volunteers were encouraged to bring their own culture to the workplace, including styles of dress and other types of informality not typical in the E ring (Carter, 2019: 331).

As discussed in Section 4.1.3, Schein and Schein's (2017) primary methods of transmitting and embedding culture highlight opportunities and disconnects that DoD leadership could address to increase the effectiveness of systems engineering. In particular, the three methods related to personnel are levers worth pulling.

1. What leaders pay attention to, measure, and control on a regular basis become the things that people in the organization use to decide how to act. Is SE effectiveness an active component of DoD leadership reviews? Are experiments to bridge R&D tech transfer to production initiated and managed at a systems level? Do leaders collaborate with tech leaders outside the DoD and share their objectives and results within the DoD? Are systems engineering successes widely acknowledged or only failures?

2. How do DoD leaders allocate rewards and status? When systems engineers and their technical project colleagues initiate breakthrough process changes, can they

expect recognition? Is the SE role valued, and if so, by whom? Does a systems engineer get recognized for doing everything “by the book”, or also for questioning the status quo? What level of empowerment and decision making systems engineers have and how are they groomed and encouraged to exercise that empowerment?

3. How do leaders recruit, select, promote, and excommunicate systems engineers? In former Secretary of Defense Carter’s “Force of the Future” initiative, he discovered that recruits of all kinds tend to come from certain regions of the US where military and government service is widespread because of military base and defense industry locations. This limits the diversity of backgrounds, experiences, attitudes, and habits of the people in these roles. Cognitive diversity, a necessity for collaborative innovation as discussed above, is harder to achieve given current recruiting practices.

When it comes to recruiting highly skilled technical people for military and civilian tech roles, the DoD also faces competition from companies that offer greater salaries, benefits, opportunities for advancement, access to leading edge tools, and informal open cultures. Bright spots include expanding scholarship-for-service programs in science and technology fields and reducing the time for applicants to get a final job offer (Carter, 2019: 387).

Another key to getting the best people to say “yes” to a DoD job offer is having potential employees get to know people already in those jobs who are excited by their work and proud of their accomplishments for the public good. Creating more opportunities for people to test the waters before committing has led to attracting people with hard-to-find skills. These easier and non-permanent “on-ramps”, like the Defense Digital Service (DDS) and expansions of the Secretary of Defense Corporate Fellow program for business leaders, can help. Similarly, in 2018 Congress passed changes to the Defense Officer Personnel Management Act of 1980 that now enable officers to accelerate their development through doctoral programs and opportunities to work in technology companies without being penalized for promotion. Since the traditional promotion system counted years spent in rank, supplementing knowledge and experience with outside activities was not an attractive option in the past (Carter, 2019: 386-387). Identifying ways to take maximum advantage of these and other programs for DoD personnel who wish to specialize in systems engineering is another path to increasing overall effectiveness.

Retention is critical to developing SE capability. The Helix data showed that in all sectors (defense, high-tech, research labs, etc.), systems engineers become more valuable to the organization as they gain experience with more types of systems, tools, and teams. Many organizations build systems engineers by design by taking domain engineers and exposing them to new domains and systems of systems challenges. As the Helix interviews showed, systems engineers in government organizations had lower morale and a lower sense of efficacy than people doing the SE role in high tech companies, which underscores some culture problems that go beyond recruitment to retention.

Former Secretary of Defense Carter summed up the central place of order, clarity, and consistency in the military tradition and culture: “One of the great cultural strengths of

the DoD is the way members of America's military, both those in uniform and civilian personnel, tend to believe in discipline; in following lawful orders; in having written rules that provide sound guidance for responding to complicated challenges; and in having a well-defined chain of command governing the making and transmittal of decisions" (Carter, 2019: 423).

Creating order, clarity, and consistency are goals of SE organizations as well. The challenge is to maintain these goals while changing the rules of interaction needed to accelerate innovation and rapid deployment of new technologies. The military found ways of maintaining these cultural principles while radically changing rules of interaction in the war on terror. The values themselves don't prevent adaptation and change; they become principles used in the conscious furtherance of change. How can government SE organizations use these values to transform their effectiveness? What are the links between order, clarity, and consistency with agility? What would order, clarity, and consistency look like behaviorally in a rapid innovation engineering team?

Looking outside the DoD, order, clarity, consistency, and discipline are not always the values corporate partners use to describe themselves. Perceived differences in values generate assumptions and judgments about the worth of the other group. As Schein and Schein (2017) discussed, espoused values can be misunderstood by outsiders unless they look more deeply at the underlying assumptions that govern the expression of those values. Understanding why people in another culture act the way they do and how the "way they do things around here" serves their goals enables groups to find commonalities and appreciate potential strengths of members of the other culture.

These deeper looks at other cultures do not happen without intention. Expanding partnerships across cultural barriers requires building structures, opportunities, and relationships where people experience the benefits and satisfaction of achieving a common goal. It also requires upfront acknowledgment that some aspects of one's culture could get in the way unless the group tries to mitigate ingrained habits and ways of thinking. In this case, openness to new approaches and the willingness to explore disagreement in new ways is needed by both corporate and government partners.

The Helix project has shown over and over that systems engineers who build relationships and learn from interacting with people across the value stream are more successful. Systems engineering leaders need to value differences and create opportunities to build understanding, respect, trust, skillful disagreement practices, and common goals where the best aspects of each organization's culture generate progress, just as former Secretary of Defense Carter modeled.

The US Military culture is well known for its commitment to learning. Making decisions with facts and logic, conducting after-action reviews across roles and levels of hierarchy, investing in training, and developing leaders are key attributes of the culture. Former Secretary of Defense Carter states, "Nothing could be more important for any future SecDef than to respect and protect the DoD's heritage as a learning organization" (Carter, 2019: 425), and he links this heritage directly to the imperative to support innovation. In his view, people must have "freedom to reflect and a decision-making process that encourages them to take well-considered risks" (Carter, 2019: 326) to ensure that results of all actions, even if not optimal, become a source of knowledge for the future. In the Helix interviews, many people recognized that systems engineering at

its best is the holder and disseminator of historical knowledge across projects, technologies, and time, and view systems engineers as key delineators of risks and possible mitigation strategies. Project managers expect systems engineers to be the technical conscience of the program.

Making the process of learning about one's own culture while engaging with people from another culture an explicit part of cross-group experiments increases the likelihood of sustained success. Part of the "systems of systems" approach of the best SE organizations will increasingly require cultural intelligence and continuous adaptive engagement with the meta-questions of "who we are and who we need to be" and "why and how we do things the way we do them around here."

---

### 5.3.2 TAKING A SYSTEMS VIEW OF CULTURE

Pisano's advice (2019 a) is to take a systems view of culture. "Because innovative cultures are systems of interdependent behaviors, they cannot be implemented in a piecemeal fashion. Think about how the behaviors complement and reinforce one another. Highly competent people will be more comfortable with decision making and accountability—and their 'failures' are likely to yield learning rather than waste. Disciplined experimentation will cost less and yield more useful information—so, again, tolerance for failed experiments becomes prudent rather than shortsighted. Accountability makes it much easier to be flat—and flat organizations create a rapid flow of information, which leads to faster, smarter decision making."

As Pisano (2019 a) remarks, most technology leaders espouse the values of innovative cultures like "tolerance for failure, willingness to experiment, psychological safety, highly collaborative, and nonhierarchical" that are supported by research but run into trouble maintaining these values in real organizations. Simply reading the Helix report and endorsing these values would not grow innovation capabilities.

Each organization must look at the countervailing beliefs, attitudes, and behaviors that make these apple-pie innovation values difficult to sustain. By investigating how the paradoxes Pisano describes operate in one's own environment and by continuously working to maintain the balance between these forces, an organization can build a culture that truly supports innovation. Systems engineering organizations can provide that leadership by:

- tolerating and learning from failure while setting, growing, and maintaining high standards for SE competence;
- willingly experimenting while using disciplined data-based decision-making processes for project and feature innovations;
- building psychological safety while insisting that all team members seek and offer honest feedback and are supported in their attempts to increase their constructive feedback skills;
- fostering a sense of collective responsibility through diverse collaborative practices while creating clarity about systems engineers' ownership and accountability for specific technical decisions;
- defining decision-making ownership at all levels so that decisions can be made in as non-hierarchical a way as possible while also grooming systems engineers to

be the big-picture, systems-of-systems thinkers who guide others with SE strategic technical vision; and

- transparently modeling and advocating for norms and behaviors that balance these paradoxes while acknowledging that creating an innovative culture is not all “fun and games” (Pisano, 2019 a, b). Innovative cultures require collective vigilance, experimentation, and continuous learning and embracing the idea that “hard” and “soft” behavior is necessary.

As the Helix team explored the literature on cultures of innovation, including Harvard professor Gary Pisano’s recent article (2019a) and book (2019b) *The Hard Truth about Innovative Cultures*, a lead member of a military innovation project in the study shared his thoughts on Pisano’s conclusions relative to government innovation. Following are some of his observations:

- His SE organization, though set up as an experiment in innovation across military, industry, and academia, did not have agreed-upon ways of assessing and using facts to change the project as new data emerged. As Pisano (2019 a) argues, “Discipline-oriented cultures select experiments carefully on the basis of their potential learning value, and they design them rigorously to yield as much information as possible relative to the costs. They establish clear criteria at the outset for deciding whether to move forward with, modify, or kill an idea. And they face the facts generated by experiments.” On this military project, once the vision was set at the highest levels, there was no way to change course, even when it was clear to most technologists that the vision needed revision. Pisano (2019 a) argues that “continuing to pursue a failed program means forgoing the opportunity to join a winning one.” Much time was wasted ignoring the data of failed experiments. Opportunities for accomplishing the bigger picture of the mission were not pursued.
- Psychological safety is not easy to create, even in an organization chartered as an innovation engine where organization learning is an imperative because of the complexity and novelty of the mission. If people from any level or part of the organization are expected to openly use data and logic to critique any idea, this must be modeled by people at all levels in the hierarchy. As Pisano (2019 a) describes, “Accepting a devastating critique of your idea is possible only if you respect the opinion of the person providing that feedback.” On a project with many remote, part-time contributors from universities, corporations, and branches of the military, building these norms of respect and open communication was a challenge.
- On this innovation project, collaboration across many organizations was essential, yet who to involve on which issues and accountability and decision-making responsibilities was at times unclear. As Pisano (2019 a) describes, “...too often, collaboration gets confused with consensus. And consensus is poison for rapid decision making and navigating the complex problems associated with transformational innovation. Ultimately, someone has to make a decision and be accountable for it. An accountability culture is one where individuals are expected to make decisions and own the consequences. Accountability and collaboration can be complementary, and accountability can drive collaboration.” If everyone knows the decisions for which they are responsible, each is motivated to seek out the judgments and advice of experts throughout the broader organization.

- This leader called attention to Pisano's (2019 a) observation that "[a]n organizational chart gives you a pretty good idea of the structural flatness of a company but reveals little about its cultural flatness—how people behave and interact regardless of official position. In culturally flat organizations, people are given wide latitude to take actions, make decisions, and voice their opinions. Deference is granted on the basis of competence, not title." Pisano continues, "Lack of hierarchy, though, does not mean lack of leadership. Paradoxically, flat organizations require stronger leadership than hierarchical ones. Flat organizations often devolve into chaos when leadership fails to set clear strategic priorities and directions... [f]or senior leaders, it requires the capacity to articulate compelling visions and strategies (big-picture stuff) while simultaneously being adept and competent with technical and operational issues." In the innovation organization in the Helix sample, senior leadership changed frequently and often a new leader would not have both the vision and the technical competence required for a nimble, flat operating environment.

If the goal is to become a more innovative organization, systems engineers must not only be part of the process, they must apply these principles to their own sub-culture as they attempt to influence the broader organization.

As Reynolds and Lewis (2018) describe, the generative behaviors seen in innovative organizations as measured by the Qi Index at the intersection of high cognitive diversity and high psychological safety include paradoxical notions similar to Pisano's results: people must embrace being forceful about ideas and actions as well as being curious, inquiring, experimental, encouraging, and nurturing. Organizations that choose to administer the Qi Index survey can use their data to discuss how best to express and balance these attributes to increase their capacity for innovation. The Qi Index along with the Pisano paradoxes provide ample conversation starters for taking a hard, data-driven look at a SE culture.

Pisano (2019a: 71) goes on to discuss:

*...too many leaders think that by breaking the organization into smaller units or creating autonomous 'skunk works', they can emulate an innovative start-up culture. This approach rarely works. It confuses scale with culture. Simply breaking a big bureaucratic organization into smaller units does not magically endow them with entrepreneurial spirit. Without strong management efforts to shape values, norms, and behaviors, these offspring units tend to inherit the culture of the parent organization that spawned them. This does not mean that autonomous units or teams can't be used to experiment with a culture or to incubate a new one. They can—But the challenge of building innovative cultures inside these units should not be underestimated. And they will not be for everyone, so you will need to select very carefully who from the parent organization joins them.*

---

### 5.3.3 THE NUANCES OF CREATING PSYCHOLOGICAL SAFETY

Adam Grant, professor at Wharton, University of Pennsylvania argues that most people are capable of novel thinking and problem solving. Instead of relying on a few exceptional people to introduce innovative thinking, bring diverse people together and expose them all to new ways of thinking, building opportunities for inquiry and

discovery, and empowering everyone to innovate. Although “building a culture of non-conformity begins with learning how to generate and vet ideas... to maintain originality over time, leaders need to keep fighting the pressures against it.” (2016a:92)

To illustrate, Grant (Grant 2016a:88) tells the story of a Navy innovation taskforce created to help form a DoD outpost in Silicon Valley—a move initiated not by the top, but by a group of junior officers. The group was led by Ben Kohlmann, seen by officers as a troublemaker, a radical and heretic who sparked the Navy’s first rapid-innovation cell by finding “black sheep” with a history of non-conformity as well as sailors who were seen as less interested in questioning the status quo but who were interested in learning about innovation.

To increase psychological safety and reduce fear when ideas are not adopted, Ben Kohlmann “rejected the military’s traditional emphasis on hierarchy. Everyone communicated on a first-name basis, ignoring rank” (Grant 2016a:94). Grant reports that Kohlmann introduced everyone to others in the Navy who had successfully generated change to show them that they could, too.

Grant suggests that to avoid the tendency for strong cultures to eventually become homogeneous and less able to respond to shifting conditions, it is necessary to create a strong supply of critical opinions. This relates to the Reynolds and Lewis (2018) Qi Index research and Gary Pisano’s (2019a) work, both of which argue for making dissent a core value and building skills in collaboration and candor. Grant quotes a member of the first Navy rapid innovation cell as saying the norm is “loyal opposition – agitating against the status quo is how we contribute to the mission” (Grant 2016a:92).

Creating psychological safety also requires equipping people with the skills to raise and discuss “undiscussables”. Several organizations interviewed on the Helix project reported the symptoms of teams struggling with undiscussables, including unresolved conflicts, uneven participation in meetings and decisions, and disengagement or low morale. Although many things can cause these symptoms, the lack of psychological safety and the belief that systems engineers had little respect or impact made it likely that important conflicts were not raised or resolved. As Toegel and Barsoux (2019:2) in “It’s Time to Tackle Your Team’s Undiscussables” describe, “the more undiscussables there are, the more difficult it is for the team to function. If they are not discussed collectively, they cannot be managed intelligently.” The result is unproductive relationships, ineffective meetings, lack of constructive debate and fact-finding, and poor decisions. For systems engineers to be maximally effective, they need the skills and the will to raise undiscussables.

Why are critical topics about projects and project cultures not discussed? Sometimes people believe that the risks of raising issues outweigh the potential benefits, especially in hierarchical organizations where prior attempts to resolve conflicts have not been received openly by others. Edmondson, the Harvard psychological safety researcher cited by Toegel and Barsoux (2019:4), “has shown a critical barrier to psychological safety is the weight of hierarchy. Power and status differences tend to discourage team members from bringing up issues or concerns they think the leader may view as disruptive or even none of their business.”

The implied status and power differences in a hierarchical organization don't need to translate into a hierarchical culture with lower psychological safety. Leaders in healthy hierarchies reduce power distance between them and all subordinates by openly soliciting ideas, welcoming feedback, allowing others to offer ideas and solutions before they advocate for a particular path, and in general modeling the norms of open communication and fact-based, inclusive decision making.

In the organizations where systems engineers were most effective in the Helix study, the SE function (or role) was explicitly valued and included in all major project decisions. Raising the status and power of the SE role is possible in any style of organization, hierarchical or otherwise. Discussing the Helix results in this report within an organization can make it safer to openly raise issues (about culture, governance practices, role and status, etc.) that decrease effectiveness. Exploring the gaps between what the organization says it values and the behaviors and structures that make realizing that value difficult enables the whole system to become more open and comfortable talking about and agreeing on change.

To remove lingering undiscussables and build a culture where new undiscussables don't accumulate, Toegel and Barsoux (2019:10) advocate building in routines where teams "pay attention not only to what they achieve but how they achieved it by working together." Having regular places and structures where "inward-focused team talk" supplements the usual "outward focused work talk" builds high performance. Systems engineers can lead these conversations within their own functions, in their projects, and across their larger organizations. In fact, the job of a systems engineer is to bring out the best from all stakeholders so that the right products can be built; their influence on the culture of communication, group learning, and decision excellence makes all the difference.

The concept of psychological safety, which has been in the social science literature for decades, has become popular to discuss in technical organizations, especially since the Google studies.

Delizonna (2017) discusses the two-year Google study that demonstrated what social psychologists have been saying for decades: "High performing teams have one thing in common: psychological safety" (2017:1). Quoting Google's Head of Industry, Paul Santagata, "In Google's fast-paced, highly demanding environment, our success hinges on the ability to take risks and be vulnerable in front of our peers." Delizonna advises creating a workplace that feels challenging (which heightens solution finding and divergent thinking) and that is not threatening (which builds the positive emotions it takes to persevere and cooperate when faced with complex problems). Systems engineers on challenging projects who feel safe to speak their minds, challenge approaches, and expand curiosity and trust among others enable their teams to thrive in uncertain, rapidly changing, and high-risk innovation environments.

How did Santagata build psychological safety at Google? According to Delizonna (2107), he built the skills in his people to do these six things:

1. Approach conflict as a collaborator, not an adversary, by always focusing on the question, "How can we achieve a mutually desirable outcome?"
2. Speak "human-to-human," which means pausing to reflect on the many ways the other person in the conflict is "just like me": they want to feel respected,

appreciated, and competent, just like me; they have beliefs, perspectives and opinions, just like me.

3. Anticipate reactions and plan countermoves: when communicating your point of view, consider likely reactions of the audience.
4. Replace blame with curiosity. “If you believe you already know what the other person is thinking, then you’re not ready to have a conversation” (2019:4). You never have all the facts.
5. Ask for feedback on how you communicated your perspective to improve communication skills and to signal your respect for the other person’s needs and competence.
6. Measure psychological safety. This is a Google hallmark where every team goal is measured. One of their survey questions is, “How confident are you that you would not receive retaliation or criticism if you admit an error or make a mistake?”

Shane Snow (2020) highlights the importance of not confusing “comfort” with psychological safety (see Figure 40). If you achieve high psychological safety by smoothing over differences and creating norms where everyone needs to feel comfortable at all times, you lose the benefits of the difference of perspectives that leads to excellent problem solving and innovation. Organization cultures that over-emphasize norms that make everyone feel comfortable at all times reduce people’s ability to say what needs to be said. Snow states, “The job of a leader is not to protect their team from discomfort. It’s to protect them from harm—and to help motivate them to push through the discomfort and harness it for growth.” This is consistent with the Human Insight finding (Lewis and Reynolds 2018) that the most innovative organizations endorse “forceful” as one of the top six descriptors of their culture. A culture that is “forceful” as well as “nurturing, encouraging, curious, experimental, and inquiring” allows for safety and the intellectual discomfort that comes from sharing differing opinions.

In the Helix interviews, organizations in the Netherlands described themselves as strong on consensus while also strong on non-hierarchical direct talk. It was “safe” to disagree vigorously during the discussion periods and to say what needed to be said to anyone in the organization. At the same time, it was understood that disagreeing was to be for the purpose of furthering understanding so that a good decision could be endorsed, eventually, by all participants. One organization was experimenting with ways to accelerate problem solving and decision making such that consensus could be achieved in less time while maintaining the healthy open debate that leads to good decisions. To that end, one company instituted a late-day decision process where all interested parties would be invited to give input to a topic that had been discussed at length previously and would be required to stay in the meeting until a decision was reached. This process reduced the time it took for decisions to be made while also acknowledging the value of disagreement in service to timely consensus decision making.



**Figure 40. Importance of Not Confusing “Comfort” with Psychological Safety (Snow, 2020)**

Psychological safety is created by all the people in the organization, not just the leaders. An individual systems engineer can build the communication mindsets and skills that lead others to trust and respect them. Systems engineering organizations can support their systems engineers as they build these skills through discussion and training. Senior leaders across an innovation organization can recognize people for these skills, model them themselves, and ensure that managers throughout the organization recognize their role in maintaining a culture of psychological safety on every project.

### 5.3.4 PERSPECTIVES ON INCREASING ORGANIZATIONAL AGILITY

Aghina, De Smet, Lackey, Lurie, and Muraka (2018) argue that the linear model of project management that emphasizes hierarchical specialization and efficiency maximization by optimizing labor tasks as machine functions does not neatly serve the dynamic environments of most industries today. The authors report four trends that indicate the end of the “management century” as we knew it. These include:

1. Quickly evolving environments: new patterns of interaction and expectations among customers, shareholders, partners, regulators, investors, and competitors result in mergers, acquisitions, and changing priorities.
2. Constant introduction of disruptive technology: digitization, machine learning, robotics, and other technology shifts are turning industries into commodities or replacing them.
3. Accelerating digitization and democratization of information: organizations must acquire, distribute, and respond to more information and collaborate with customers, partners, and teammates in new ways.
4. The new war for talent: creative knowledge and continual learning are more important and the talent pool is more diverse, which means companies must

attract different people and create organizations where they can retain the best talent.

In their research, Aghina et.al. (2018: 7-19) describe five “trademarks” of agile organizations:

1. Strategy: North star embodied across the organization: shared purpose and vision, sensing and seizing opportunities, flexible resource allocation, and actionable strategic guidance.
2. Structure: Network of empowered teams: clear, flat structure; clear accountable roles; hands-on governance; robust communities of practice; active partnerships and ecosystem; open physical and virtual environment; and fit-for-purpose accountable cells.
3. Process: Rapid decision and learning cycles: rapid iteration and experimentation; standardized ways of working; performance orientation; information transparency; continuous learning; and action-oriented decision making.
4. People: Dynamic people model that ignites passion: cohesive community; shared and servant leadership; entrepreneurial drive; and role mobility.
5. Technology: evolving technology architecture, systems, and tools; and next-generation technology development and delivery practices.

These five trademarks are interrelated and form a system and mindset where the mission: gives people clear indicators of how to be responsive and responsible without the need for high-level leaders to provide detailed plans; and allows people to operate with a level of accountability and empowerment without narrow silos and deep hierarchies.

The Helix observations are consistent with these “trademarks” that offer special support to SE capability. Many systems engineers described the benefits of:

- Systems engineering end-to-end accountability and team interaction across the lifecycle.
- Systems engineering communities of practice to rapidly grow expertise in emerging tools and methods.
- Systems engineering technologies integrated in everything; for example, Model Based Systems Engineering tools not as support but as a “means to unlock value” (Systems engineering tools that are used after the fact to simply document the requirements determined by developers instead of tools used to drive the requirements decision process were described as examples of failures of successful technology integration.)
- Cross-functional decision accountability. Especially in the Netherlands, systems architects were often part of a triumvirate of equal decision makers with project management and development peers.
- Systems engineering capability is enhanced through continuous learning, which gives system engineers access to project and process knowledge through the life cycle of a project and across projects over time. Where systems engineers perceive their role to be “the conscience of the project,” organizations support continuous learning.
- Systems engineers whose role involves being technical communicators benefit from establishing standardized ways of working, especially when they are

involved in establishing communication practices across the project life cycle and across projects.

---

## 5.4 EFFECTIVENESS MEASURES

Neither the team nor any of the participants in the study have found a way to separate systems engineering's contribution from the contribution of disciplines like program management or other engineering disciplines. Studies like Elm et al. (2007) highlight that a higher systems engineering capability correlated with improved project performance. But, so did a number of other factors. In fact, overall systems engineering capability was seen as a "moderately strong positive" influence on project performance, while things like "requirements and technical solution combined with project challenge" and "combined requirements and technical solution" in the project approach had a significantly stronger positive correlation. Likewise, Gruhl's analysis of systems engineering expenditures and cost overruns indicate a correlation between systems engineering expenditures and reductions in cost overruns – up to a point. (Stutzke 2005) After about 20% of total program cost is invested in SE, it does not appear that further investment in SE activities reduces the risk of cost overrun. Both studies highlight the need for systems engineering, but neither completely disentangles systems engineering from other factors because the activities of systems engineering are too entangled with project activities around design and management.

One of the aspirations of the Helix team was to develop a quantitative assessment of effectiveness – precise metrics that would definitively determine whether an organization is or is not effective at systems engineering. This proved to not be possible for a variety of reasons. First, when the team asked individuals about the metrics used to assess effectiveness, the most common responses were around the iron triangle: cost, schedule, and quality. Much like the Elm and Gruhl work, the contribution of systems engineering from other disciplines could not be fully disentangled from systems engineering's contribution. Second, when individuals could discuss benefits of systems engineering, they aligned well with the values delivered by systems engineers identified in earlier Helix work, with indications about the way the organization does nor does not enable these values. This led the team to approach the problem more qualitatively, and resulted in the values outlined in *Atlas* and highlighted in Table 6 (next section).

In terms of assessing effectiveness, the Helix team found that the most consistent way to assess was whether the values were assessed consistently across the organization and over time. For Helix, an organization achieves an effective systems engineering capability when the values highlighted above are consistently delivered. For Helix, consistency has two metrics: 1. consistency across the organization, and 2. consistency over time. Consistency across the organization can be tailored based on the organization's structure. For example, this could be by project: if the values outlined above are consistently delivered across a variety of projects, that would indicate high effectiveness. If the organization delivers these values inconsistently, either by delivering only a few values or only a few projects deliver these values, this is an indication of ineffective systems engineering. Likewise, organizations that deliver these values at some times but not others are less effective. Plotting this consistency and understanding how it changes over time gives an organization insights into its progress towards systems engineering effectiveness. (see Figure 41)

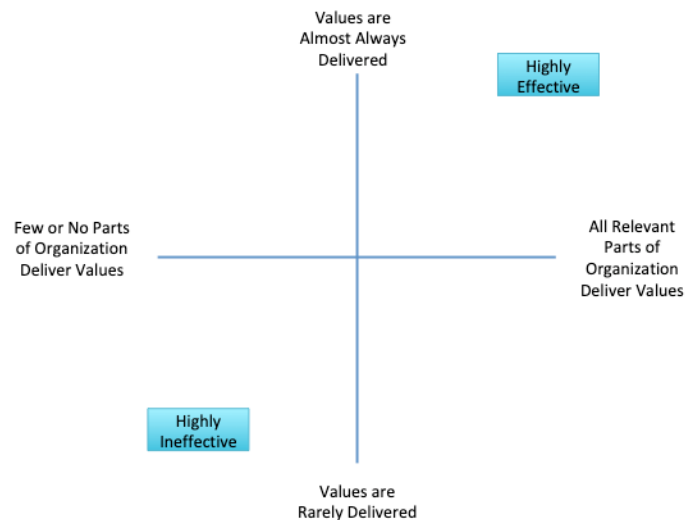


**Figure 41. Consistent Delivery of Systems Engineering Values**

In 2019, INCOSE released the “Model Based Enterprise Capability Maturity Matrix”, designed to help organizations assess the maturity specifically of their MBSE capabilities. (Hale and Hoheb, 2019) Like most of the competency models around systems engineering examined by the team, the Maturity Matrix is structured around a series of attributes and the degree to which these attributes are met, with “stage 0” meaning the capability does not exist and “stage 4” meaning that the capability is fully mature. Though this language is not used explicitly, the “stage 4” capabilities reflect that MBSE is woven into the organization’s policies, processes, procedures, and methods and supported by the organization’s leadership and infrastructure. In other words, MBSE is part of the governance, structure, and MPTs of the organization. Though the matrix does not use this language, the Helix team’s assessment is that the Maturity Matrix indicates that an organization with a “fully mature” MBSE capability would be one that has integrated MBSE into the culture – the way things are done there. In this sense, the Maturity Matrix aligns well with the Helix findings and approach.

## 6 CONCLUSIONS

---

At the end of the period of performance in July 2020, the team has accomplished the following:

- updated the self-assessment tools and website;
- developed the organizational assessment tool; and
- completed the study of organizational attributes that affect the effectiveness of the SE workforce.

---

### 6.1 RESEARCH QUESTIONS

The way that Helix measures effectiveness is to assess – and have the organization assess – how consistently SE values are delivered over time. This provides an aggregate profile that reflects overall capability. Though less quantitative than initially hoped, this approach has proven both understandable and a useful way to assess and have conversations in organizations.

- How does the effectiveness of the SE workforce impact the overall ability of an organization to successfully deploy increasingly complex systems and solutions (i.e., to have an effective SE capability)?
  - Strongly. Without individuals who are proficient at systems engineering, an organization cannot have an effective systems engineering capability. There are some organizations that do not have explicit systems engineers and instead SE roles are distributed; this works when specific roles are clearly owned and is less effective when “everyone is a systems engineer”, but there is no clear owner of systems engineering.
- What critical factors, in addition to individual workforce effectiveness, are required to enable SE capability? Factors include tools, practices, processes, policies, and culture. Engineering is a social event, so the means of aggregating individual capabilities is critical.
  - All of the variables hypothesized by the Helix team impacted effectiveness to some extent. However, culture was the strongest and most pervasive influencer. It is common in an engineering environment for improvement efforts to focus on MPTs, training programs, and the like. All of these are valuable. But the cultural context in which SE activities are happening is critical. Culture influences all of the other factors in addition to directly impacting systems engineers. Efforts to improve SE that do not also address culture will not yield the desired results.
- How do the variables that impact SE effectiveness need to shift to enable different SE approaches?
  - Every organization that the Helix team worked with used similar systems engineering approaches – usually described as the “Vee model” or “waterfall model”. Occasionally, an organization was

working on moving towards more model-centric systems engineering activities. However, there was not enough variation in the data to draw strong conclusions about the different SE approaches, except to say that integration with and utilization of software engineering approaches may be useful (see below).

---

## 6.2 SUMMARY OF KEY FINDINGS

Following is a recap and summary of findings from the analyses:

- Systems engineers and others are ready, willing, and able to think about and discuss how systems engineering is working in their organizations and what needs to be done to improve effectiveness. Ask them!
- There are likely to be perception differences among systems engineers, their managers, and other stakeholders. Increasing transparency of perceptions is an important step to collective improvement in conditions, expectations, and results.
- Organization culture variables that encourage free discussion, empowerment to make decisions, and respect for the SE discipline have a positive effect on effectiveness.
- Structure and governance variables such as limiting silo behavior and having seats at the highest-level decision tables may increase effective communication and data-driven decisions.
- Having tools, training, and high-quality, experienced systems engineers in key roles matter, especially for projects in highly complex and rapidly changing industry or mission contexts.
- Designing, using, and customizing processes that fit the needs of the project and the stakeholders lead to acceptance of SE expertise and increases value.
- Leaders, be they SE managers, project managers, or senior leadership team members, who champion the value of systems engineers and the systems engineering discipline within the organization, motivate and retain systems engineers while also enabling them to consistently deliver value.
- Given the global nature of most large-scale SE enterprises, it is important to use a global research approach to understand the geographic and cultural differences in: a) the perceived desirability and need for a dedicated SE workforce vs. a distributed SE expertise capability embedded in other roles; b) the perceived value of different teaming structures, decision practices (consensus, hierarchical, etc.), and approaches to constructive conflict; and c) preferences for pragmatic and situational approaches vs. preferences for structured and rule-driven approaches to problem solving.

From an organizational perspective, some of the most important lessons organizations can learn from the Helix finding (previously discussed in Section 4) are repeated in Table 6.

Table 6. Organizational Impacts on Effectiveness

| Six Primary SE Values                                                           | Ways Organizations Have Positive Impacts on Effectiveness                                                                                                                                                                                                                                                                                                                                                                                                                                                                                | Ways Organizations Have Negative Impacts on Effectiveness                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         |
|---------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 1. Keep and maintain system vision                                              | Support customer and stakeholder access through the lifecycle of a project.                                                                                                                                                                                                                                                                                                                                                                                                                                                              | <ul style="list-style-type: none"> <li>Although most organizations believe Model-Based System Engineering (MBSE) is important, many feel MBSE is not well understood within and across functions. Early MBSE implementations have not always demonstrated the full value of the approach, and teams have had difficulty getting buy-in from developers to make full use of the methods.</li> <li>The “agilization” of software has become an expected and valued approach to software engineering, but now companies struggle to make similar speed and flexibility advances in hardware domains. This is seen by many as the next frontier for complex system design and delivery, and people are looking to SE to advance the cause.</li> </ul> |
| 2. Translate technical jargon into business or operational terms and vice versa |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   |
| 3. Enable diverse teams to successfully develop systems                         | <ul style="list-style-type: none"> <li>Keep key people in place, and invest in knowledge transfer for people (SEs and others) who must rotate in and out of projects.</li> <li>Staff teams with cognitively diverse people.</li> <li>Designing, using, and customizing processes that fit project and stakeholders needs lead to acceptance of SE expertise and increases value.</li> <li>Support high-value repeatable processes while also seeking and sensibly implementing innovation and flexibility in process and tool</li> </ul> | <ul style="list-style-type: none"> <li>Constant personnel changes undermine efficiency, and the quick succession of leaders undermines mission clarity on projects that require long-term focus.</li> <li>Conflict occurs when different mindsets simultaneously operate on a project. The military or operations mindset values speed and action and conflicts with the SE mindset that values data-driven decision making, process integrity, and testing.</li> <li>System complexity requires different skills, tools, and strategic</li> </ul>                                                                                                                                                                                                |

|                                                        |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    |
|--------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
|                                                        | <p>choices.</p> <ul style="list-style-type: none"> <li>• Set an organization-wide standard for behaviors that drive psychological safety.</li> <li>• Ensure aligned role clarity of SEs across the organization.</li> <li>• Effectiveness correlates with people's views about how generative the culture is: curious, encouraging, experimental, forceful, inquiring, and nurturing.</li> <li>• Cultures that value and build individual and group collaboration skills (CVF Clan Cultures) may be viewed as effective (not enough data).</li> </ul> | <p>approaches than currently commonly available. These organizations find it difficult to hire systems engineers with cutting-edge knowledge and tool experience, and often don't have the time, money, and expertise to acquire the tools they'll need as systems get more complex and schedules get shorter.</p> <ul style="list-style-type: none"> <li>• Software has become more central to products of all kinds. Systems engineers, however, often come from hardware backgrounds and do not have the needed software experience or depth of knowledge. Similarly, leaders of SE organizations typically have hardware engineering backgrounds and are seen as not adapting to the changing priorities of software/hardware development.</li> <li>• Though most people view their organizations to be evolving, only those that see this evolution as being positive ("improving") believe the SE organization is effective. Cultures viewed as hierarchical, cautious, and conforming are less likely to be viewed as effective.</li> </ul> |
| 4. Manage emergence in both the project and the system | <p>Dedicate resources for SE to reach out to other organizations (internal and external) that are advancing the discipline as the field and complexity of projects change.</p>                                                                                                                                                                                                                                                                                                                                                                        | <ul style="list-style-type: none"> <li>• Keep projects in tight silos, removing opportunities for cross-project learning, reuse, platform development, systems thinking, and future awareness.</li> <li>• Organizations struggle with finding the balance between investing in platform development and focusing on the immediate and unique needs of individual projects. SE organizations "know" they need better road maps and reuse of designs, but often do not have the organizational backing to invest time and expertise in forward planning and integration.</li> </ul>                                                                                                                                                                                                                                                                                                                                                                                                                                                                  |

|                                                                |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      |
|----------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <p>5. Enable good technical decisions at the systems level</p> | <ul style="list-style-type: none"> <li>• Continually push down hierarchy and increase empowerment enabling proficient SEs to own key decisions.</li> <li>• Actively educate technical and managerial communities about the expertise, roles, and value of SEs, which would in turn increase the respect of, reliance on, and accountability by SEs.</li> <li>• Include proficient SEs in decision forums across the life cycle of projects and in the development of cross-project platforms and roadmaps.</li> <li>• Use SE skills in making data-driven decisions.</li> </ul> | <ul style="list-style-type: none"> <li>• Schedule focus can override using important SE processes limiting SE contributions and jeopardizing quality.</li> <li>• In the government organizations studied, systems engineers did not feel respected, valued, understood, or championed.</li> <li>• Given the common practice of government projects using contract organizations for critical products components, they sometimes struggle to maintain internal SE skills when most of the SE work is being done by contractors. SE excellence is necessary in government organizations to ensure systems-of-systems integrity and provide direction for the contract SEs.</li> </ul> |
| <p>6. Support the business case for systems</p>                | <ul style="list-style-type: none"> <li>• Listen to SEs when making major tradeoffs among cost, schedule, quality, customer requirements, system reliability, manufacturability, test, repair, etc.</li> <li>• Cultures that look outward (CVF external focus and differentiation) combine product vision with customer focus and seek innovative ways to find and use new resources.</li> </ul>                                                                                                                                                                                 |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      |

To support individuals and organizations in implementing the findings of Helix, the team has developed two tools:

- Self-Assessment Tool – allows individuals to assess their knowledge, skills, and abilities as well as their career path, track progress over time, and set targets for development.
- Organizational Assessment Tool – allows organizations to set up their employees to provide data on organizational culture, structure, governance, and systems engineering. The tool provides basic analysis based on employee feedback and allows tracking of trends over time.

The tools as well as all major Helix findings and reports are posted to [helix-se.org](https://helix-se.org) to enable individuals and organizations to transition the research findings into practice.

## 7 RECOMMENDATIONS

---

**How Organizations Can Use This Research.** This research identifies tools organizations can use to analyze and reflect on their SE capabilities, which will enable them to make better decisions and investments to grow their SE capability.

Following are some methods to consider applying to your organization:

- Review this report with the leaders of the organization. Highlight relevant findings. Ask the leaders to design methods for applying the data and/or the tools to the organization.
- Initiate discussion in your organization about the main drivers of SE effectiveness and the barriers to effectiveness the organization has constructed over time. For example, hold a workshop session with systems engineers and others; ask small groups to discuss and prioritize responses to the main questions of effectiveness, culture, governance and structure, process, tools, and bright spots; combine the lists, compare to the Helix findings, and identify opportunities for fast fixes and priorities for continued attention.
- Gather anonymous data from your organization using a subset of the questions used in the Helix survey (Appendix E). We recommend using any of the systems engineering specific questions plus the Qi Index from Human Insight<sup>2</sup>. Review the data with groups in the organization to prioritize the recommended actions and ensure follow through.
- Use the Qi Index culture assessment to assess variations in perceptions in different segments of your organization and across different levels of leadership. How strong is the subgroup's cognitive diversity and psychological safety? Do leaders view the organization differently than individual contributors? Do systems engineers use the same words to describe the state of the organization as others? Look at patterns to find bright spots that other parts of the organization may be able to learn from and to find which subgroups or relationships need more attention. By starting with the big picture, organizations may then choose one of the above methods for further data collection, analysis, and collective action. This tool, as a repeatable standardized method, can be used to monitor change over time as people define and implement improvements.
- Seek out peer organizations in your industry sector to share common tensions and solutions. Take a system view of organization capability by learning from and with organizations experiencing similar internal and external forces.
- Require or enable systems engineers to develop and contribute to communities of practice within and across companies / industries/ sectors.

To support individuals and organizations in continuing the research, the Helix team has created tools (described in Section 3) that are available at [helix-se.org](https://helix-se.org).

---

<sup>2</sup> For questions about the Qi Index, please contact Zeldi Storni at Human Insight: [zstorni@human-insight.com](mailto:zstorni@human-insight.com) or +31 (0) 85 8229827

## REFERENCES

---

- Aghina, W., De Smet, A., Lackey, G., Lurie, M., & Muraka, M. (2018). The five trademarks of agile organizations. Available at <https://www.mckinsey.com/business-functions/organization/our-insights/the-five-trademarks-of-agile-organizations>
- Andres, E., & Peterson, T. (2008). Systems Engineering Capability Development, Presentation at the NDIA 11<sup>th</sup> Annual Systems Engineering Conference. Available at <https://ndiastorage.blob.core.usgovcloudapi.net/ndia/2008/systems/7423andres.pdf>
- Bird, S., & Klein, E. (2006). Regular Expressions for Natural Language Processing. Available at [http://courses.ischool.berkeley.edu/i256/f06/papers/regexps\\_tutorial.pdf](http://courses.ischool.berkeley.edu/i256/f06/papers/regexps_tutorial.pdf)
- BKCASE Editorial Board. (2017). *The Guide to the Systems Engineering Body of Knowledge (SEBoK)*, v. 1.9. R.D. Adcock (EIC). Hoboken, NJ: The Trustees of the Stevens Institute of Technology. Available at [www.sebokwiki.org](http://www.sebokwiki.org).
- BKCASE is managed and maintained by the Stevens Institute of Technology Systems Engineering Research Center, the International Council on Systems Engineering, and the Institute of Electrical and Electronics Engineers Computer Society.
- Blei, D. M., Ng, A. Y., & Jordan, M. I. (2003). Latent dirichlet allocation. *Journal of machine Learning research*, 3(Jan), 993-1022.
- Cameron, K. S., & Quinn, R.E. (2011). *Diagnosing and changing organization culture based on the competing values framework* (3<sup>rd</sup> ed.). San Francisco, CA: Jossey-Bass.
- Cameron, K. S., & Quinn, R. E. 2011. *The Competing Values Culture Assessment: A Tool from the Competing Values Product Line*. Retrieved from: <http://cf2015.bhcarroll.edu/files/session-1-congregational-development/quinn-and-cameron-organizational-culture-assessment-instrument.pdf>
- Carter, A. (2019). *Inside the Five-Sided Box: Lessons from a Lifetime of Leadership in the Pentagon*. New York, NY: Dutton.
- Davidz, H.L. (2006). *Enabling Systems thinking to Accelerate the Development of Senior Systems Engineers*. Dissertation, Doctor of Philosophy in Engineering Systems, Massachusetts Institute of Technology.
- Delizonna, L. (August 24, 2017). High-performing teams need psychological safety. Here's how to create it. *Harvard Business Review*. <https://hbr.org/2017/08/high-performing-teams-need-psychological-safety-heres-how-to-create-it>
- Dettmer, H.W. (2011). "Systems Thinking and the Cynefin Framework", Goal Systems International. Available at <https://static1.squarespace.com/static/578d0f8459cc6877481865ef/t/57ec5284579fb363a5b9a18c/1475105417186/Systems-Thinking-and-the-Cynefin-Framework-Final.4.pdf>

- DoD. (2010). DoD Architecture Framework (DoDAF), version 2.02, Washington, DC, USA: US Department of Defense (DoD). Available at [https://dodcio.defense.gov/Library/DoD-Architecture-Framework/dodaf20\\_glossary/](https://dodcio.defense.gov/Library/DoD-Architecture-Framework/dodaf20_glossary/)
- Elm, J. P., et al. (2007). A Survey of Systems Engineering Effectiveness – Initial Results. Software Engineering Institute and NDIA. Available at [https://resources.sei.cmu.edu/asset\\_files/SpecialReport/2007\\_003\\_001\\_14801.pdf](https://resources.sei.cmu.edu/asset_files/SpecialReport/2007_003_001_14801.pdf)
- Ernst, C., & Chrobot-Mason, D. (2011). Flat world, hard boundaries – How to lead across them. *MIT Sloan Management Review*, Spring 2011.
- Firth, M. (1979). Impact of work experience on the validity of student evaluations of teaching effectiveness. *Journal of Educational Psychology*, 71(5), 726-730.
- Fisher, D., Hoff, A., Robertson, G., & Hurst, M. (2008). Narratives: A visualization to track narrative events as they develop. In Visual Analytics Science and Technology, 2008. VAST'08. IEEE Symposium on (pp. 115-122). IEEE.
- Ford, J. K., Smith, E. M., Sego, D. J., & Quinones, M. A. (1993). Impact of task experience and individual factors on training-emphasis ratings. *Journal of Applied Psychology*, 78(4), 583-590.
- GAO. (2008). “Defense Acquisitions: Assessments of Selected Weapon Programs”. Government Accountability Office (GAO). GAO-08-467SP.
- GAO. (2011). “Weapons Acquisition Reform: Actions Needed to Address Systems Engineering and Developmental Testing Challenges”. Government Accountability Office (GAO). GAO-11-806.
- GAO. (2012). “Weapons Acquisition Reform: Reform Act Is Helping DOD Acquisition Programs Reduce Risk, but Implementation Challenges Remain”. Government Accountability Office (GAO). GAO-13-103.
- GAO. (2013). “High Risk Series: An Update”. Government Accountability Office (GAO). GAO-13-283.
- GAO. (2018). “Federal Acquisitions: Congress and the Executive Branch Have Taken Steps to Address Key Issues, but Challenges Endure”. Government Accountability Office (GAO). GAO-18-627.
- Goldberg, Y., & Levy, O. (2014). word2vec Explained: deriving Mikolov et al.'s negative-sampling word-embedding method. *arXiv preprint arXiv:1402.3722*.
- Gordon, G. W. (1985). *The relationship between corporate culture and industry sector and corporate performance*. In Kilmann, R. H. and Associates, *Gaining control of corporate culture*. San Francisco: Jossey-Bass.
- Grant, A. (2016 a). How to build a culture of originality, *Harvard Business Review*, March 2016 pp 86-94, Reprint # R1603H
- Grant, A. (2016 b). *Originals. How non-conformists move the world*. New York: Viking.
- Henshaw, M. J. C., et al. (2014). Capability Engineering - An Analysis of Perspectives. INCOSE 21<sup>st</sup> International Symposium, 20-23 June, 2011, Denver, USA.
- Hofstede, G. (1980). *Culture's consequences*. Thousand Oaks, CA: Macmillan.

Hofstede, G. (2020). Country Comparison Between the Netherlands and the USA.

Available from <https://www.hofstede-insights.com/country-comparison/the-netherlands,the-usa/>

Hutchison, N., Verma, D., Burke, P., Clifford, M., Giffin, R., Luna, S., & Partacz, M. (2018). *Atlas 1.1: An update to the Theory of Effective Systems Engineers*. Hoboken, NJ: Systems Engineering Research Center, Stevens Institute of Technology.

Hutchison, N., Verma, D., Burke, P., Clifford, M., Giffin, R., Luna, S., & Partacz, M. (2018b). *Atlas Career Path Guidebook: Patterns and Common Practices in Systems Engineer's Development*. Hoboken, NJ: Systems Engineering Research Center, Stevens Institute of Technology.

Hutchison, N., Verma, D., Burke, P., Giffin, R., See Tao, H. Y., Yu, Z., Chen, X., Makwana, D., Xiao, Y. (2020). *Atlas: Effective Systems Engineers and Systems Engineering*. Hoboken, NJ: Systems Engineering Research Center, Stevens Institute of Technology.

INCOSE. (2018). "Systems Engineering Competency Framework". Available at <https://www.incose.org/products-and-publications/competency-framework>

Kets de Vries, M. F. R., & Miller, D. (1986). *Personality, culture, and organization. Academy of Management Review*, 86:11, 266-279.

Kirschenbaum, S. (1992). Influence of experience on information-gathering strategies. *Journal of Applied Psychology*, 77(3), 343-352.

Kotter, J. P., & Heskett, J. L. (1992). *Corporate culture and performance*. New York: Free Press.

Martin, J. (1992). *Cultures in organizations*. New York: Oxford University Press.

Metzger, L.S., & Bender, L.R. (2007). MITRE Systems Engineering Competency Model. Retrieved June 24, 2011 from: [http://www.mitre.org/work/systems\\_engineering/guide/10\\_0678\\_presentation.pdf](http://www.mitre.org/work/systems_engineering/guide/10_0678_presentation.pdf).

Mikolov, T., Sutskever, I., Chen, K., Corrado, G. S., & Dean, J. (2013). Distributed representations of words and phrases and their compositionality. In *Advances in neural information processing systems* (pp. 3111-3119).

Monet, R. (2014). *What is the clan or collaborative culture in franchising?*. Zoracle, October 2, 2014. Available at <https://www.zoracleprofiles.com/what-is-the-collaborative-culture-in-franchising/>

Monet, R. (2014a). *What is the creative culture (adhocracy) in franchising?*. Zoracle, November 1, 2014. <https://www.zoracleprofiles.com/what-is-the-creative-culture-adhocracy-in-franchising/>

NASA (2009). Systems engineering competencies. Retrieved September 29, 2011 from: [http://www.nasa.gov/pdf/303747main\\_Systems\\_Engineering\\_Competencies.pdf](http://www.nasa.gov/pdf/303747main_Systems_Engineering_Competencies.pdf)

Pisano, G. P. (2019). *The Hard Truth About Innovative Cultures. Harvard Business Review*. Available at <https://hbr.org/2019/01/the-hard-truth-about-innovative-cultures>

Pyster, A., Olwell, D.H., Ferris, T.L.J., Hutchison, N., Enck, S., Anthony, J., Henry, D., & Squires, A. (eds.). 2012. *Graduate Reference Curriculum for Systems*

- Engineering* (GRCSE™). Hoboken, NJ, USA: The Trustees of the Stevens Institute of Technology. Available at [www.bkcase.org/grcse/](http://www.bkcase.org/grcse/)
- Pyster, A., Henry, D., Hutchison, N., Lasfer, K., & Rifkin, S. (2013a). "*The Helix Project*". Systems Engineering Research Center, Stevens Institute of Technology. SERC-2013-TR-038-1, May 20, 2013.
- Pyster, A., Hutchison, N., & Henry, D. (2018). *The Paradoxical Mindset of Systems Engineers: Uncommon Minds, Skills, and Careers*. Hoboken: Wiley.
- Pyster, A., Pineda, R., Henry, D., & Hutchison, N. (2013b). "*Helix – Phases 1 and 2*". Systems Engineering Research Center, Stevens Institute of Technology. SERC-2014-TR-038-2, December 20, 2013.
- Pyster, A., Pineda, R., Henry, D., & Hutchison, N. (2014). "*Helix – Phase 3*". Systems Engineering Research Center, Stevens Institute of Technology. SERC-2014-TR-038-3, April 19, 2014.
- Reynolds, A., & Lewis, D. (2017). *Teams solve problems faster when they are more cognitively diverse*. *Harvard Business Review*, March 30, 2017. <https://hbr.org/2017/03/teams-solve-problems-faster-when-theyre-more-cognitively-diverse>
- Reynolds, A., & Lewis, D. (2018). *The two traits of the best problem-solving teams*. *Harvard Business Review*, April 2, 2018. <https://hbr.org/2018/04/the-two-traits-of-the-best-problem-solving-teams>
- Royce, W. (1970). "*Managing the Development of Large Software Systems*" (PDF), *Proceedings of IEEE WESCON*, 26 (August): 1-9.
- SEBoK Authors. "Lifecycle Stages" in Cloutier, R. 2020. *The Guide to the Systems Engineering Body of Knowledge (SEBoK)*, v. 2.2. Robert Cloutier (EIC). Hoboken, NJ: The Trustees of the Stevens Institute of Technology. Accessed 01 June 2020 [www.sebokwiki.org](http://www.sebokwiki.org)
- BKCASE is managed and maintained by the Stevens Institute of Technology Systems Engineering Research Center, the International Council on Systems Engineering, and the Institute of Electrical and Electronics Engineers Computer Society. (Note: This term has since been removed from the glossary in v. 1.9.)
- Schein, E. H. (1983). *Organizational Culture*. *Organizational Dynamics*, 83:12, 13-28.
- Schein, E. H. (2010). *Organizational Culture and Leadership* (4th ed.). San Francisco: Jossey-Bass.
- Schein, E. G., & Schein, P. (2017). *Organizational Culture and Leadership* (5th ed.). Hoboken, NJ: John Wiley & Sons, Inc.
- Schmidt, F. L., Hunter, J. E., & Outerbridge, A. N. (1986). Impact of job experience and ability on job knowledge, work sample performance, and supervisory rating of job performance. *Journal of Applied Psychology*, 71(3), 432-439.
- Sheard, S. (1996). "Twelve Systems Engineering Roles." Proceedings of the International Council on Systems Engineering (INCOSE) Sixth Annual International Symposium, 7-11 July 1996, Boston, MA.

- Sheard, S. (2000). "The 12 Systems Engineering Roles Revisited." Paper presented at the INCOSE Mid-Atlantic Regional Conference. April 2000. Reston, VA, USA. pp. 5.2-1 - 5.2-9.
- Snow, S. (2020). *How psychological safety actually works*. Forbes Magazine. May 4, 2020. Available at <https://www.forbes.com/sites/shanesnow/2020/05/04/how-psychological-safety-actually-works/#e6dd88df864c>
- Stanchev, L. (2015). Semantic search using a similarity graph. In Semantic Computing (ICSC), 2015 IEEE International Conference on (pp. 93-100). IEEE.
- Stutzke, R. (2005). *Estimating Software-Intensive Systems*. Boston, MA, USA: Addison Wesley.
- Swensen, S., & Mohta, N. S. (2018). *MEJM Catalyst Leadership Survey Why Big Gaps in Organizational Alignment Matter*. NEJM Catalyst, March 2018.
- Toegel, G., & Barsoux, J.L. (Fall 2019). It's time to tackle your team's undiscussables. *MIT Sloan Management Review, Blog* September 10. 2019.
- Walter, P. G. (2013). *"A Model for Effective Systems Engineering Workforce Development at Space and Naval Warfare Systems Center (SSC) Atlantic"*. Master Thesis. Naval Postgraduate School, Monterey, CA.

**APPENDIX A: LIST OF PUBLICATIONS**

---

Book Publication

Pyster, A., Hutchison, N., & Henry, D. (2018). *The Paradoxical Mindset of Systems Engineers: Uncommon Minds, Skills, and Careers*. Hoboken, NJ: Wiley.

Conference Papers and Presentations

Burke, P., Hutchison, N., Giffin, R., 2019. "Helix: Developing an Understanding of Organizational Systems Engineering Effectiveness", ESI Symposium presentation, Eindhoven, The Netherlands, April 9, 2019

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

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

Hutchison, N., 2018. "Helix: Developing an Understanding of Organizational Systems Engineering Effectiveness." Presentation at the NDIA Annual Systems Engineering Conference, Tampa, FL, October 22-25, 2018

Hutchison, N., 2018. "Helix: Developing an Understanding of Organizational Systems Engineering Effectiveness." Presentation at the SERC Sponsor Research Review, Washington, D.C., November 8, 2018

Hutchison, N., Burke, P., See Tao, H. Y., Giffin, R., Verma, D., Makwana, D., 2019. "Update on the Helix project: Understanding Organizational Attributes that Make Systems Engineering Organizations Effective", 11th Annual SERC Sponsor Research Review, Washington, DC, November 19, 2019

Hutchison, N., Burke, P., See Tao, H. Y., Kothari, S. J., Makwana, D., Luna, S., 2019. "The Influence of Organization Alignment on the Effectiveness of Systems Engineers", Conference on Systems Engineering Research (CSER), Washington, D.C.

Hutchison, N., Burke, P., See Tao, Y., Giffin, R., Verma, D., Makwana, D., 2020. "Investigating Organization Attributes that Support Systems Engineering Workforce Effectiveness," 30th Annual INCOSE International Symposium, Cape Town, South Africa, August 2020

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

- Hutchison, N., Henry, D., Pyster, A., Dominick, P., 2014(b). "Systems Engineering Career Analysis: Supporting a Theory of Systems Engineers." Proceedings of the Europe, Middle East, and Asia Sector Systems Engineering Conference, Cape Town, South Africa, October 27-30, 2014
- Hutchison, N., Henry, D., Pyster, A., Pineda, R., 2014. "Early Findings from Interviewing Systems Engineers who Support the US Department of Defense." Proceedings of the 2014 International Council on Systems Engineering (INCOSE) 24<sup>th</sup> International Symposium, Las Vegas, NV, June 30-July 3, 2014
- Hutchison, N., See Tao, H. Y., Burke, P., Luna, S., 2019. "Evolution of the Helix Project: From Investigating the Effectiveness of Systems Engineers to Systems Engineering Organizations", International Council on Systems Engineering (INCOSE) International Symposium, Orlando, FL
- Hutchison, N., Wade, J., Luna, S., 2017. "The Roles of Systems Engineers Revisited." Proceedings of the International Council on Systems Engineering (INCOSE) 27<sup>th</sup> International Symposium, Adelaide, Australia, July 15-20, 2017
- Jauregui, C., Pyster, A., Henry, D., Hutchison, N., Wright, C., 2016. "Insights on the Experiences and Education of INCOSE-Certified Expert Systems Engineering Professionals and Chief Systems Engineers." Proceedings of the International Council on Systems Engineering (INCOSE) 26<sup>th</sup> International Symposium, Edinburgh, Scotland, July 18-21, 2016
- Lipizzi, C., Manchanda, S., Kamil, M., Pyster, A., Henry, D., Hutchison, N., 2015. "The Education Background of INCOSE Systems Engineering Professional Certification Program Applicants." Proceedings of the International Council on Systems Engineering (INCOSE) International Symposium, Seattle, WA, July 2015
- Luna, S., Partacz, M., Hutchison, N., 2018. "Discovering Career Patterns in Systems Engineering." Proceedings of the International Council on Systems Engineering (INCOSE) International Symposium, Washington, D.C., July 7-12, 2018
- Pyster, A., Hutchison, N., 2015. "The Helix Project: Analysis of INCOSE SE Certification Program Applicants." Special Presentation to the International Council on Systems Engineering (INCOSE) Corporate Advisory Board (CAB), January 25, 2015 as part of the INCOSE International Workshop, Los Angeles, CA, January 25-27, 2015
- Pyster, A., Hutchison, N., Henry, D., Barboza, C., 2015. "Helix: What Makes Systems Engineers Effective?" Proceedings of the Conference on Systems Engineering Research (CSER), 2015, Hoboken, NJ, March 17-19,
- Pyster, A., Pineda, R., Henry, D., Hutchison, N., 2013. "Helix: Investigating the DNA of the Systems Engineering Workforce." Proceedings of the National Defense Industrial Association (NDIA) Systems Engineering Conference, Crystal City, VA, October 28-31, 2013
- Pyster, A., Rifkin, S., Henry, D., Lasfser, K., Hutchison, N., Gelosh, D., 2013. "The Helix Project: Understanding the Systems Engineers who Support the US Department

of Defense." Proceedings of the Asia-Pacific Conference on Systems Engineering (APCOSE), Yokohama, Japan, September 8-11, 2013

Soneji, S., Kothari, S. J., Luna, S., See Tao, H. Y., Zavala, A., Hutchison, N., 2019. "Text Analysis Approach to Systems Engineers' Effectiveness in an Organization", IEEE Systems Conference, Orlando, FL

Squires, A., Wade, J., Hutchison, N., 2016. "Building a Pathway to Systems Education for the Global Engineer." Proceedings of the American Society for Engineering Education (ASEE) 123<sup>rd</sup> Annual Conference, New Orleans, LA, June 26-29, 2016

Yu, Z., See Tao, H. S., Xiao, Y., Burke, P., Makwana, D., Hutchison, N., 2020. "Multi-Level Systems Engineering Analyzer Dashboard: A Semi-Automated Content Analysis for Interview Data," to the IEEE Systems Conference, July 2020

### Capstone Project

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

### Dissertation

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

### Journal Articles

Zavala, A., Soneji, S., Kothari, S., Ramirez-Marquez, J. E., See Tao, H. Y., & Hutchison, N. (2020). Systems Engineers' Effectiveness in an Organization: Text and Visual Analytics Approach. *IEEE Systems Journal*.

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

### Technical Reports

Hutchison, N., D. Henry, D. Verma, M. Clifford, A. Pyster. 2016. *Atlas: The Theory of Effective Systems Engineers, version 1.0*. Hoboken, NJ: Systems Engineering Research Center, Stevens Institute of Technology. 16 December 2016.

Hutchison, N., D. Henry, D. Verma, M. Clifford, R. Giffin, A. Pyster. 2016. *The Development of Atlas: The Theory of Effective Systems Engineers*. Hoboken, NJ: Systems Engineering Research Center, Stevens Institute of Technology. SERC-2016-TR-118. 16 December 2016.

Hutchison, N., D. Verma, P. Burke, M. Clifford, R. Giffin, S. Luna, M. Partacz. Atlas *Career Path Guidebook: Patterns and Common Practices in Systems Engineers'*

- Development*. Hoboken, NJ: Systems Engineering Research Center, Stevens Institute of Technology. SERC-2018-TR-101-C. 16 January 2018.
- Hutchison, N., D. Verma, P. Burke, M. Clifford, R. Giffin, S. Luna, M. Partacz. *Atlas 1.1: An Updated to the Theory of Effective Systems Engineers*. Hoboken, NJ: Systems Engineering Research Center, Stevens Institute of Technology. SERC-2018-TR-101-A. 16 January 2018.
- Hutchison, N., D. Verma, P. Burke, M. Clifford, R. Giffin, S. Luna, M. Partacz. *Atlas 1.1 Implementation Guide: Moving from Theory into Practice*. Hoboken, NJ: Systems Engineering Research Center, Stevens Institute of Technology. SERC-2018-TR-101-B. 16 January 2018.
- Hutchison, N., D. Verma, P. Burke, M. Clifford, R. Giffin, S. Luna, M. Partacz. *RT-173: Helix – 2017 Helix Technical Report*. Hoboken, NJ: Systems Engineering Research Center, Stevens Institute of Technology. SERC-2018-TR-101. 16 January 2018.
- Pyster, A., D. Henry, N. Hutchison, C. Jauregui, M. Clifford. 2015. *Atlas: The Theory of Effective Systems Engineers, version 0.5*. Hoboken, NJ: Systems Engineering Research Center, Stevens Institute of Technology. SERC-2015-TR-108. 1 December 2015.
- Pyster, A., N. Hutchison, D. Henry, C. Jauregui, M. Clifford. 2015. *Extending Atlas to Non-Defense Systems Engineers and to Classic Engineers*. Hoboken, NJ: Systems Engineering Research Center, Stevens Institute of Technology. SERC-2015-TR-110. 18 December 2015.
- Pyster, A., P. Dominick, D. Henry, N. Hutchison, C. Lipizzi, M. Kamil, S. Manchanda. 2014(b). *Atlas: The Theory of Effective Systems Engineers*, v. 0.25. Hoboken, NJ: Systems Engineering Research Center, Stevens Institute of Technology. SERC-2014-TR-038-4. 21 November 2014.
- Pyster, A., R.L. Pineda, D. Henry, N. Hutchison. 2013. *Helix – Phases 1 and 2*. Hoboken, NJ: Systems Engineering Research Center, Stevens Institute of Technology. SERC-2013-TR-038-2.
- Pyster, A., R.L. Pineda, D. Henry, N. Hutchison. 2014. *Helix – Phase 3*. Hoboken, NJ: Systems Engineering Research Center, Stevens Institute of Technology. SERC-2014-TR-038-3.

### Workshop Reports

- Hutchison, N., D. Verma, P. Burke, H.Y. See Tao, R. Giffin, Z. Yu, D. Makwana, Y. Xiao. 2019. *Report on the Helix Transition Workshop*. 20 July 2019, in Conjunction with the INCOSE IS, Orlando, FL
- Hutchison, N., D. Verma, P. Burke, M. Clifford, S. Luna, M. Partacz, R. Giffin. *Report on the 4<sup>th</sup> Annual Helix Workshop*. 4<sup>th</sup> Annual Helix Workshop, 17 October 2017, MITRE Campus, McLean, VA
- Hutchison, N., D. Verma, R. Giffin, M. Clifford, A. Pyster. 2016. *Report on the Helix Early Adopter's Workshop*. Helix Early Adopter's Workshop, 20 September 2016, Ronald Reagan International Trade Center, Washington, D.C.
- Pyster, A., D. Henry, N. Hutchison, C. Jauregui, J. Armstrong, M. Clifford. 2015. *Report on the Second Helix Workshop: Exploring the Theory of Systems Engineers'*

*Effectiveness*. Hoboken, NJ: Systems Engineering Research Center, Stevens Institute of Technology

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

Other

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

INCOSE Symposium 2019, Orlando, FL – INCOSE Panel on professional development for the 2019 INCOSE International Symposium. Dr. Nicole Hutchison presented on Helix career paths.

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

Hutchison, N. Northrop Grumman INCOSE Community of Practice Webinar on Helix. 27 February 2018. Nicole Hutchison delivered a webinar, an overview of *Atlas*, with Q&A.

## APPENDIX B: GLOSSARY

---

Consistency in the definition and understanding of terminology and concepts is essential for any deliberation. This section presents the definitions and classifications that are relevant to *Atlas*. Some have been obtained from available literature, while others have been created specifically for *Atlas*.

---

### ACRONYMS AND ABBREVIATIONS

|           |                                                                       |
|-----------|-----------------------------------------------------------------------|
| CSE       | Chief Systems Engineer                                                |
| CVF       | Competing Values Framework                                            |
| DIB       | Defense Industrial Base (supports DoD)                                |
| DIU       | Defense Innovation Unit                                               |
| DoD       | US Department of Defense                                              |
| GRCSE     | Graduate Reference Curriculum for Systems Engineering                 |
| INCOSE    | International Council on Systems Engineering                          |
| IR&D      | Internal (or Independent) Research & Development                      |
| MBA       | Master of Business Administration                                     |
| MBSE      | Model Based Systems Engineering                                       |
| MPT       | Methods, Processes, and Tools                                         |
| OCAI      | Organizational Culture Assessment Instrument                          |
| OUSD(R&E) | Office of the Under Secretary of Defense for Research and Engineering |
| Qi Index  | Quality of Interaction Index                                          |
| R&D       | Research and Development                                              |
| SA/SD     | Systems Architects/Systems Designers                                  |
| SE        | Systems Engineering                                                   |
| SERC      | Systems Engineering Research Center                                   |
| SEBoK     | <i>Guide to the Systems Engineering Body of Knowledge</i>             |
| SME       | Subject Matter Expert                                                 |
| STEM      | Science, Technology, Engineering, and Mathematics                     |
| UARC      | University-Affiliated Research Center                                 |

---

### ATLAS DEFINITIONS

- **Systems Engineer**

*A **Systems Engineer** is an individual who performs systems engineering activities and is recognized (either formally or informally) by his or her organization for her ability to perform these activities.*

This definition of a systems engineer does *not* refer to the title that someone may hold in her organization. Someone may never hold the title 'Systems

Engineer’ but could be considered to be one based on the activities she performs. Similarly, someone may hold the title ‘Systems Engineer’ but her activities may not be systems engineering activities.

- **Effective Systems Engineer**

*An **Effective Systems Engineer** is someone who consistently delivers value by performing systems engineering activities in positions assigned by the organization.*

This definition is fundamental to *Atlas* since the focus of Helix research is the effectiveness of systems engineers. Though ‘effectiveness’ is a subjective term, this definition ties it to ‘value’ that can be defined and even measured, qualitatively, if not quantitatively.

- **Chief Systems Engineer (CSE)**

*A **Chief Systems Engineer (CSE)** is one who has formal responsibility to oversee and shepherd the technical correctness and to maintain a consistent vision for a system, often coordinating with many other systems engineers who have smaller scopes of responsibility.*

The Chief Systems Engineer (CSE) position is one of the most senior technical positions that system engineers can achieve while staying in a technical track (as opposed to a management track). Though the title ‘Chief Systems Engineer’ is not used in all organizations, the concept of a CSE position (or equivalent) is common, especially in industry. There is no consistent description of a CSE’s (or equivalent’s) formal authority, but overall responsibility for a system is often split in some way between the CSE and the project or program manager (PM).

- **Position**

*A **Position** held by an individual is equivalent to a ‘title,’ where the organization defines what roles and responsibilities it entails.*

This definition of a position is usually specific to an organization and does not translate across organizations.

- **Role**

*A **Role** performed by an individual consists of a specific set of related activities.*

Typically, an individual performs multiple roles in any given position. In the context of *Atlas*, the roles of interest are systems engineering roles.

- **Career Path**

*An individual’s **Career Path** is the precise combination (in terms of characteristics, timing, and order) of experiences, mentoring, and education and training that they undergo during their entire career.*

This definition, created for *Atlas*, is different from how career paths are typically defined in the human resources (HR) community. HR definitions tend to be

focused on rigid hierarchy that may be useful for HR classification and management of positions within an organization. However, they provide little insight into the growth and development of individuals throughout their career, particularly across organizations.

- **Proficiency**

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

In *Atlas*, the term ‘proficiency’ is used broadly to include everything that an individual needs to be good at in order to be an effective systems engineer. This distinguishes *Atlas* from competency models that tend to focus primarily on the discipline of systems engineering.

---

## **ATLAS CLASSIFICATIONS**

- **Seniority of a Systems Engineer**

As systems engineers traverse the path of their careers from the point of entry into the workforce (or recruitment) to the point or exit from the workforce (or retirement), there is a continual maturation that is reflected in the breadth and depth of their proficiencies, the types of roles and positions they play, and the value that they provide or that is expected from them. Grouping systems engineers under some levels of ‘seniority’ that reflect the levels of maturation enables patterns to be identified across systems engineers, and insights to be drawn from them.

Helix has identified three levels of seniority in systems engineers: junior, mid-level, and senior. Traditionally, ‘number of years of work experience’ has been used as a preliminary criterion for distinguishing between these levels of seniority, but it fails to capture the nuances of differentiation within systems engineers. Hence, it is not included in Table 6 that states various criteria used to distinguish between junior, mid-level, and senior systems engineers. These criteria are meant to be indicative and not rigid; there are always examples of specific individuals whose seniority is not consistent with these criteria.

**Table 7. Criteria for Distinguishing the Seniority of Systems Engineers**

| <b>Criteria for Distinguishing the Seniority of Systems Engineers</b> |                                                                                                                                          |                                                                                                                                                  |                                                                                                                                       |
|-----------------------------------------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------|
| <b>Criteria</b>                                                       | <b>Junior</b>                                                                                                                            | <b>Mid-level</b>                                                                                                                                 | <b>Senior</b>                                                                                                                         |
| <b>Leadership</b>                                                     | Primarily works as an individual contributor; has had zero or one formal leadership positions, which can be as an official supervisor or | Has had at least two formal leadership positions over teams or tasks of significant size and scope; viewed as a leader in a project, program, or | Three or more formal leadership positions over teams or tasks of significant size and scope, including second-level management roles; |

|                   |                                                                                                                                                                           |                                                                                                                                                                                                                                                  |                                                                                                                                                                                                                                                    |
|-------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
|                   | as a task leader                                                                                                                                                          | business unit of the larger enterprise                                                                                                                                                                                                           | viewed as a leader in the enterprise                                                                                                                                                                                                               |
| <b>Complexity</b> | Relevant experiences on a simple project, system, or task, working primarily at the system components level or simple activities such as managing a requirements database | Relevant experiences on moderately complex projects or systems, working at the sub-system and system levels or on moderately complex activities such as managing the development and negotiation of requirements for a moderately complex system | Relevant experiences on complex projects or systems, working at the system and platforms/systems of systems levels or on quite complex activities such as managing the development and negotiation of requirements for a complex system of systems |
| <b>Lifecycle</b>  | Relevant experiences in at least two phases of the system's lifecycle                                                                                                     | Relevant experiences in at least three phases of the system's lifecycle                                                                                                                                                                          | Relevant experiences in at least four phases of the system's lifecycle                                                                                                                                                                             |
| <b>Roles</b>      | Worked on up to three different roles                                                                                                                                     | Worked on four to six different roles                                                                                                                                                                                                            | Worked on seven to 15 different roles                                                                                                                                                                                                              |

With respect to Table 7:

1. Experience is considered to be 'relevant' if it directly supports the growth of systems engineering proficiencies.
2. A leadership position is 'formal' if it is officially defined and recognized by the organization. This does not mean that the individual necessarily has organizational authority over the individuals she is leading. Likewise, there is no defined minimal team size. Typically, early leadership positions are over small teams (less than five people) and as the individual matures, the size of the teams increases.
3. The hierarchy of system levels (components -> subsystems -> systems -> system of systems) is based on definitions from the *Guide to the Systems Engineering Body of Knowledge* (BKCASE Authors 2016) and reflects system complexity and completeness, where 'parts' at any level are combined to form the 'whole' at the next level.
4. The various aspects of the system's lifecycle are based on definitions from the *Guide to the Systems Engineering Body of Knowledge* (BKCASE Authors 2017), and are elaborated in Section 6.1.
5. The roles are based on the 15 systems engineering roles defined in *Atlas*.

Formal education, titles, and roles are *not* considered to be distinguishing criteria, since they cannot be used to consistently draw any distinctions between levels of seniority of systems engineers. However, as a baseline, systems engineers typically have an undergraduate degree in a STEM (science, technology, engineering, and mathematics) field.

## APPENDIX C: COMPETING VALUES FRAMEWORK (CVF)

The Competing Values Framework (CVF) is a culture assessment tool developed by Kim S. Cameron and Robert E. Quinn (2011) that is measured by the OCAI. Hundreds of organizations have utilized the CVF over two decades to understand and describe main cultural characteristics that relate to organization success. Scholars' theoretical and empirical works on organization culture, including Schein (1983; 2010), Kotter and Heskett (1992), Ernst (1985), Gordon (1985), Hofstede (1980), Kets de Vries and Miller (1986), Martin (1992), and Campbell, Bownas, Peterson, and Dunnette (1974), contributed to the framework's dimensions. Figure 42 shows the major dimensions and brief descriptions of the CVF, which include the clan, adhocracy, hierarchy, and market cultures. The four cultural types in the CVF and survey assessment are used to identify organizations based on the organization's orientation, leader type, values that drive their organizations, and the theory of effectiveness within the organizations. The culture could be optimal based on the work performed in each organization.

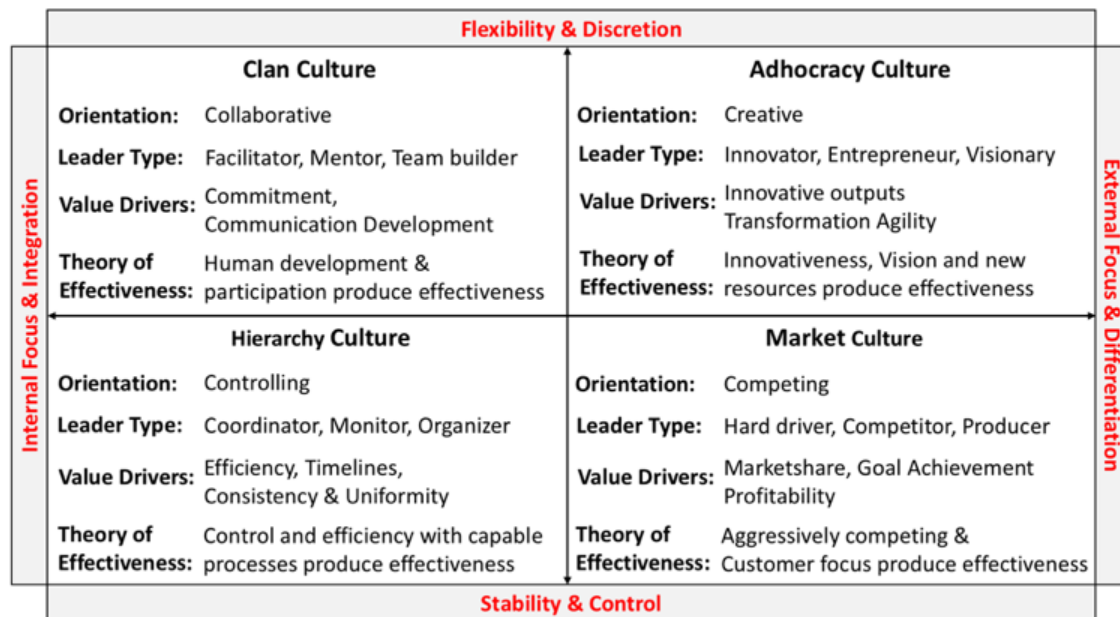


Figure 42. Competing Values Framework adapted from Cameron and Quinn (2011)

With special permission granted by Kim S. Cameron and Robert E. Quinn, the CVF was incorporated in the Helix web-based surveys to investigate the culture types and their impacts on the organization's ability to deliver systems engineering capabilities. These culture types were measured by a six-item survey based on the OCAI; members of the culture divided 100 points among four alternative statements for each of six items, indicating the extent to which each alternative is like their organization (Cameron and Quinn, 2011). The six items were dominant characteristics, leadership, management of employees, organization "glue," strategic emphasis, and criteria of success. Table 8 provides an example of the OCAI current profile for the dominant characteristics.

**Table 8. Example of the OCAI current profile for dominant characteristics (Cameron and Quinn, 2011, pp. 30, used with permission)**

| Dominant Characteristics                                                                                                                          | Now | Future |
|---------------------------------------------------------------------------------------------------------------------------------------------------|-----|--------|
| A. The organization is a very personal place. It is like an extended family. People seem to share a lot of themselves.                            |     |        |
| B. The organization is a very dynamic and entrepreneurial place. People are willing to stick their necks out and take risks.                      |     |        |
| C. The organization is very results oriented. A major concern is with getting the job done. People are very competitive and achievement oriented. |     |        |
| D. The organization is a very controlled and structured place. Formal procedures generally govern what people do.                                 |     |        |
| TOTAL                                                                                                                                             |     |        |

Once participants assessed how the culture operates “now,” the process was repeated to indicate which characteristics will ensure high performance in the “future.” The “now” and “future” culture assessments in the CVF tool enabled the participants to provide a metric for the current perceived “fit” of the characteristics to the emerging needs of the organization. The CVF can be used to identify approaches to organizational design, life cycle development stages, organizational quality, theories of effectiveness, leadership roles, and management skills (Cameron and Quinn, 2011, pp. 35). The culture assessment data could be used to plan future changes and increase overall cultural awareness within an organization.

The Helix team obtained permission to use the OCAI instrument in this research from Kim Cameron on June 4, 2018. The OCAI is available free of charge to research groups. If organizations choose to compare their culture data with the Cameron database of more than 10,000 organizations and 100,000 individuals across five continents, they can purchase additional data collection and comparisons from BDS, Behavioral Data Services, 734-663-2990, Sherry.Slade@b-d-s.com.

## APPENDIX D: QUALITY OF INTERACTION INDEX (QI INDEX)

---

The Qi Index is a culture assessment method that focuses primarily on organization behaviors, emotions, and cultural traits that are associated with the ability to adapt and innovate (Reynolds and Lewis, 2017). The Qi Index was developed by Reynolds and Lewis with a norm database of more than 100 organizations across 25 industries and 20 countries. Key factors measured include cognitive diversity and psychological safety, which are shown to relate to organization adaptability and innovation. The Qi Index consists of 18 statements rated for the extent to which they describe the organization, and three questions in which participants choose descriptive words about: 1) how they feel about the organization; 2) the behaviors they see in their organization; and 3) the current state of the organization.

The goal of the Qi Index assessment is to identify which behaviors support an organization's generative capabilities in terms of ideas, processes, and learning, and which behaviors undermine or hinder innovation. For instance, organizations use the Qi Index to enhance their strategy planning and execution, and to develop teams and leaders. The best problem-solving teams are psychologically safe and cognitively diverse, i.e., their behavior is generative (Reynolds and Lewis, 2018). Some words are consistently associated with generative organizations while others are consistently associated with less generative or less innovative teams in prior research. The results of the Qi Index give teams and organizations ideas for how to shift the culture, if desired. (Reynolds and Lewis, 2017; 2018).

At a House of Representatives hearing, "Promoting DOD's Culture of Innovation," Dr. Michael Griffin argued that the increasingly global R&D landscape requires DoD to place a premium on the speed at which it can develop and field new capabilities.<sup>3</sup> The Helix team chose the Qi Index in part because it specifically incorporates assessment of teaming that fosters or inhibits innovation. This method also facilitates the understanding of the systems engineering culture within the organization. The results of the Qi Index will describe the predominant workforce behaviors in the organization and the level of agreement or alignment among organization members. These data can be used by the organizations to better understand how they operate and to see areas for future development.

In addition, the Qi Index data will be integrated with OCAI culture data to test whether combining an overall culture assessment method with an interpersonal team dynamics method can provide specific suggestions for organization actions that could enhance performance. Since both instruments are publicly available, any organization in this research may choose to expand their use across their organization after receiving the Helix analysis. This gives participating organizations ownership of their own development once Helix concludes and an opportunity to re-test themselves to check progress after implementing targeted change.

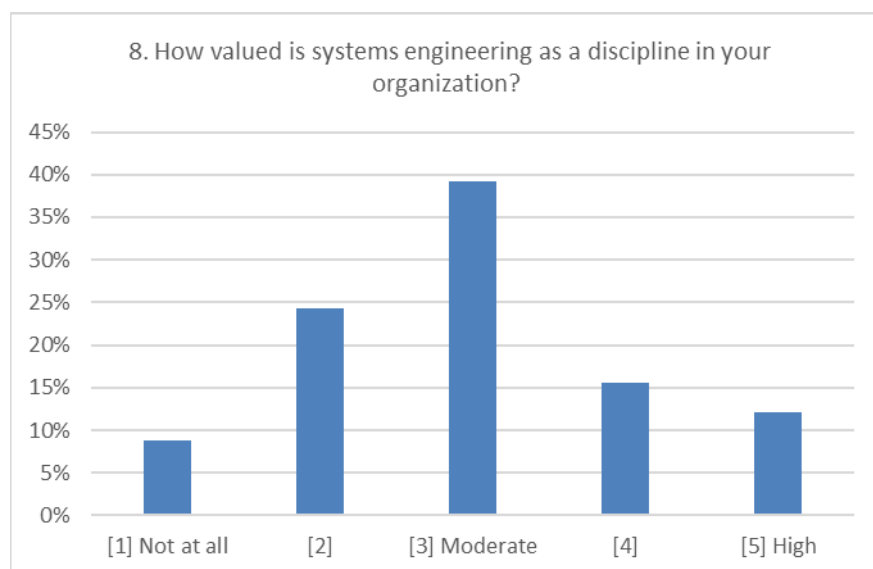
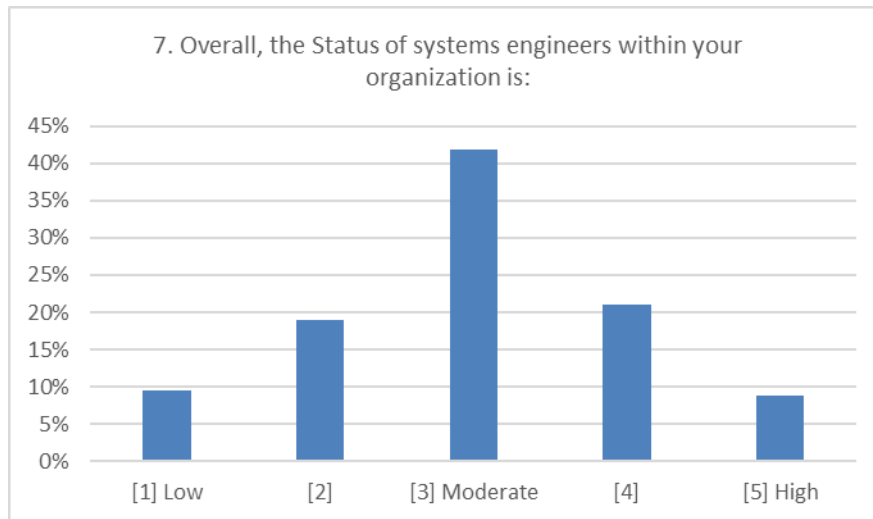
---

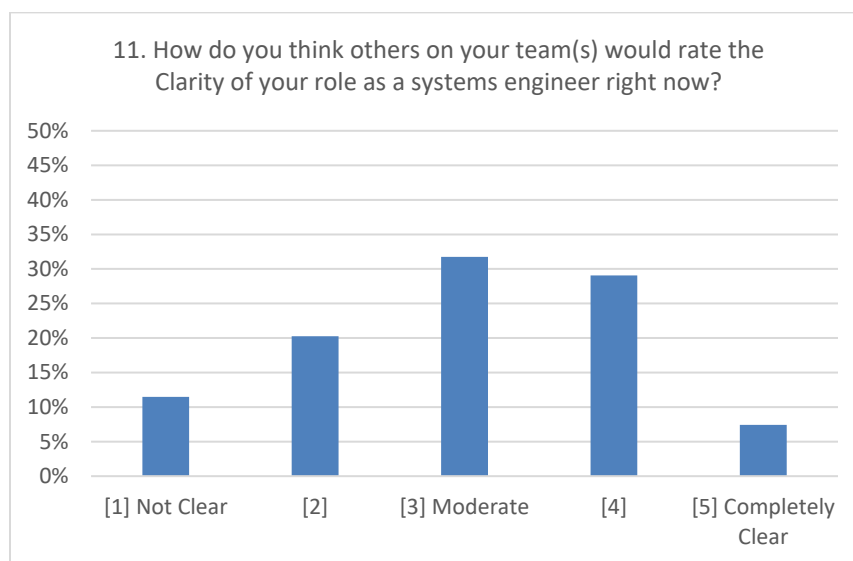
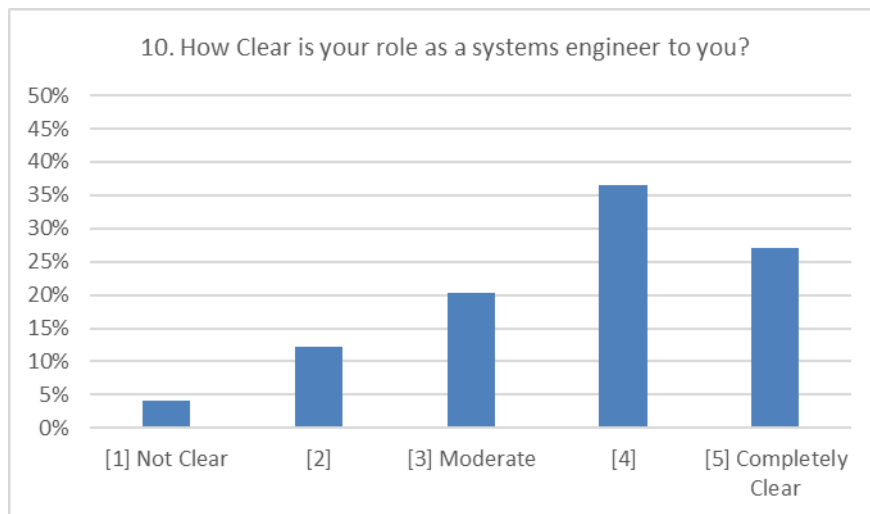
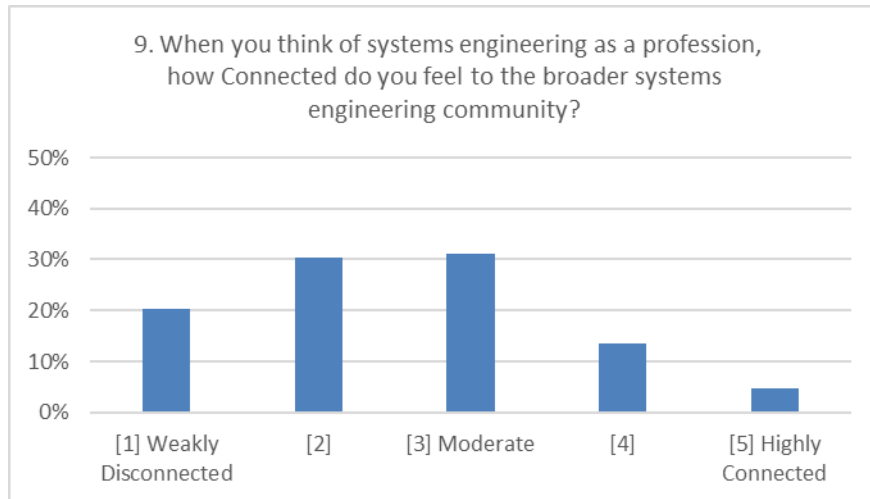
<sup>3</sup> <https://www.aip.org/fyi/2018/new-dod-rd-chief-outlines-vision-jumpstarting-military-innovation>

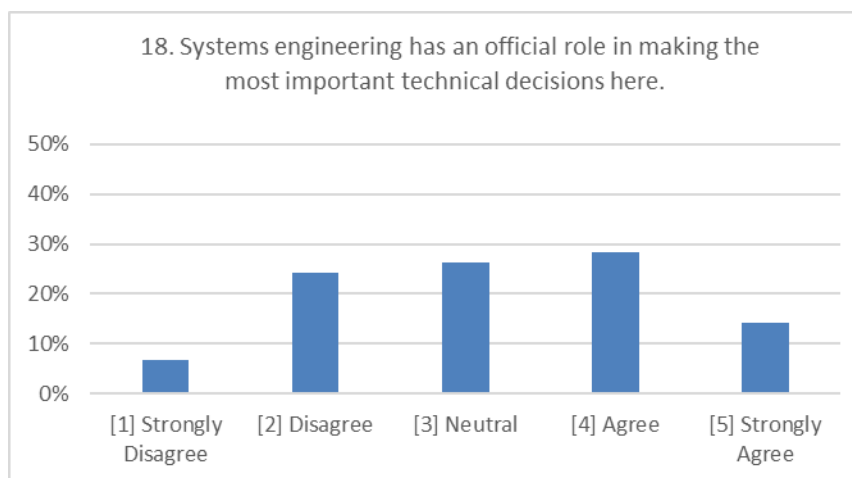
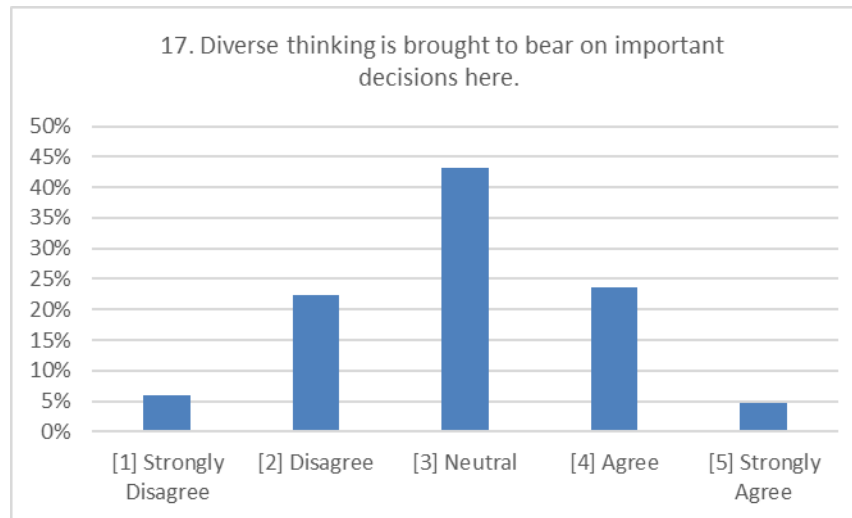
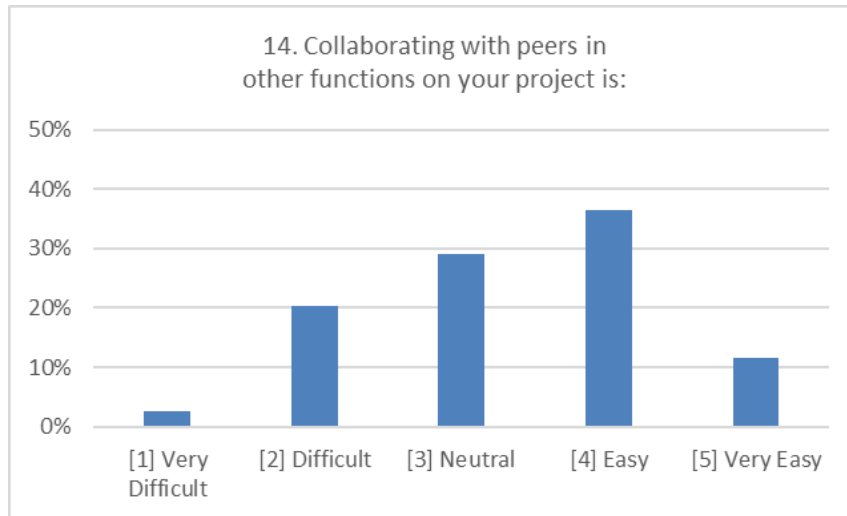
Finally, the Helix team has paired with Human Insight, the organization that oversees the global dataset for the Qi Index. Human Insight runs the data collected from each organization against its global database to provide clear comparisons against other organizations in the same industry. This provides valuable insights and baselining for participating organizations and also helps the Helix team understand whether there are critical differences among organizations that place an emphasis on systems engineering in a domain; in other words, it is an indicator of how generalizable these results may be.

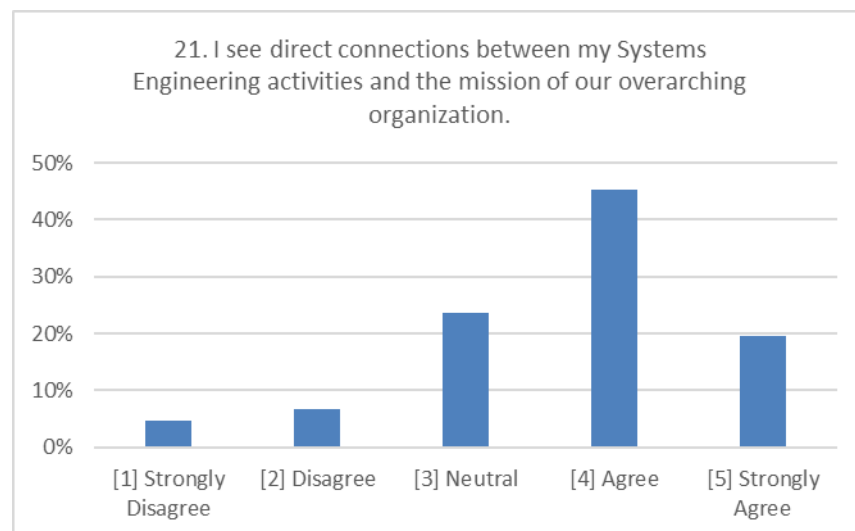
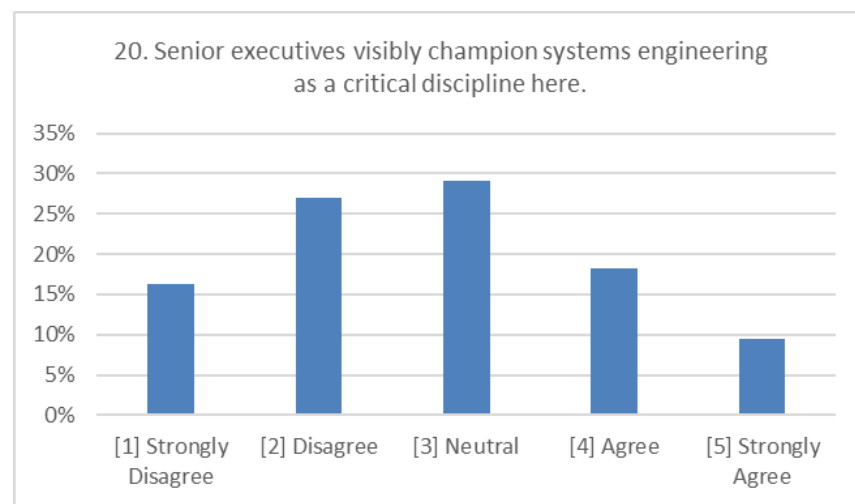
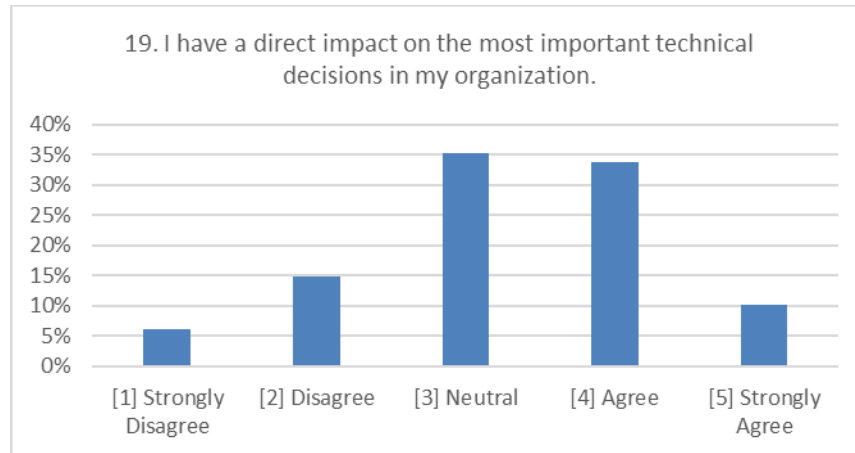
## APPENDIX E: FULL RESULTS OF THE SYSTEMS ENGINEERS' SURVEY

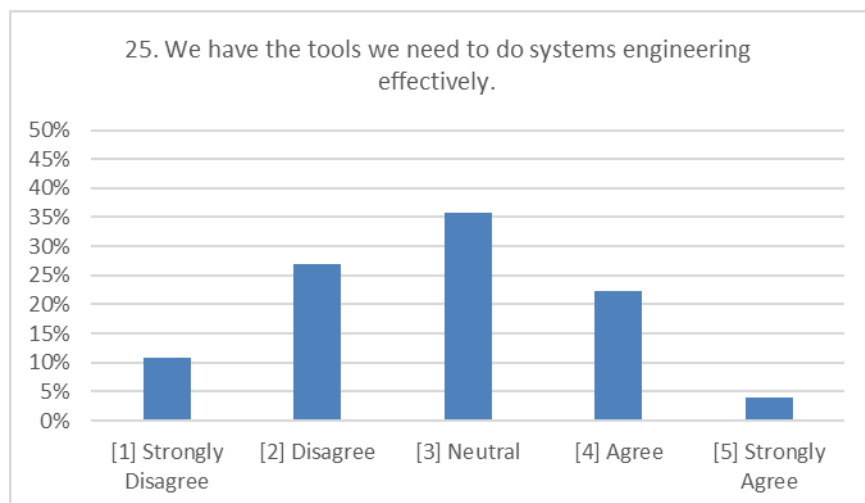
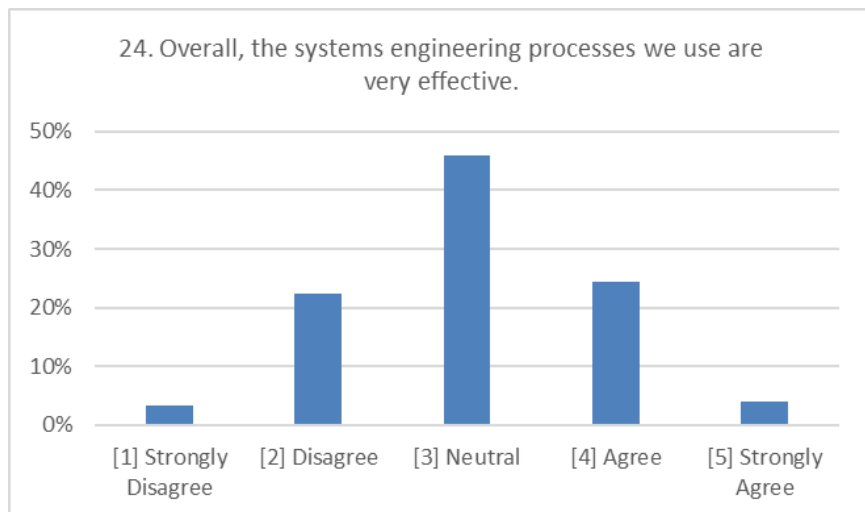
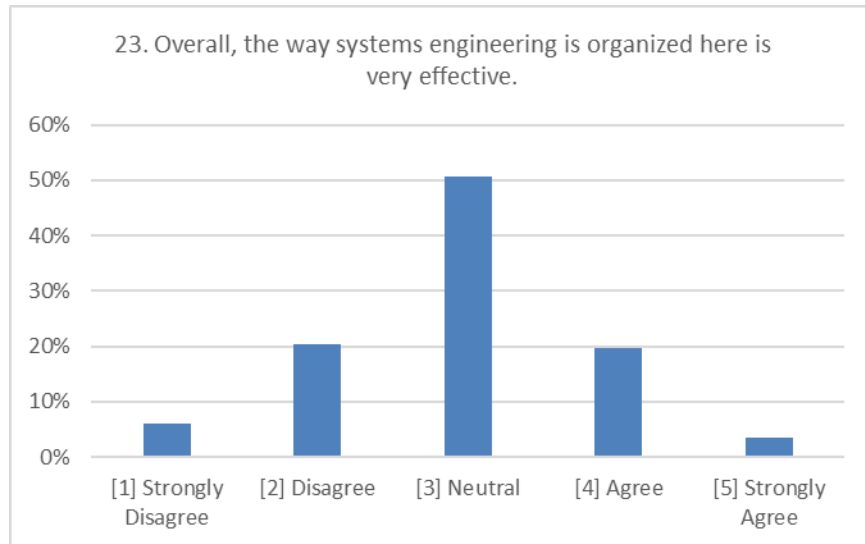
The following are overall analysis across the full dataset for the survey of systems engineers. Note: Questions 1-6 are the OCAI tool for the CVF, and Questions 34-55 are the Qi Index, which are not repeated here since the organization-focused insights were shared in the Helix Findings Section.

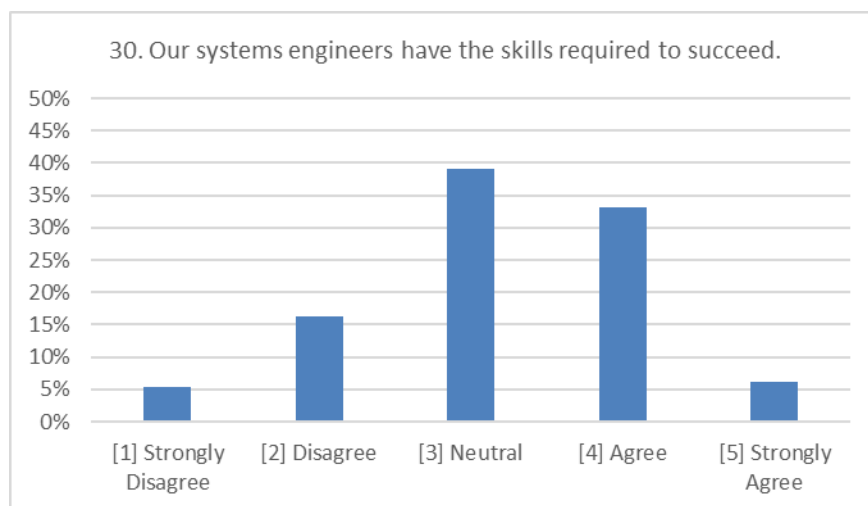
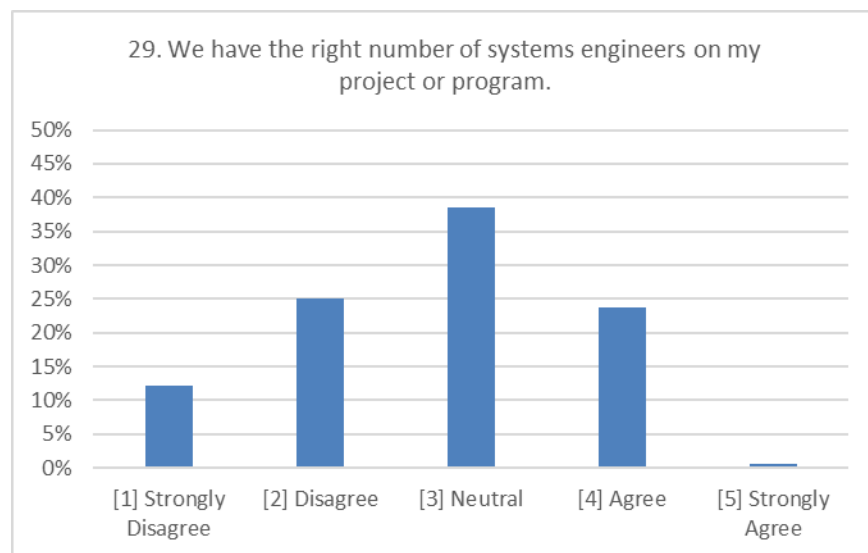
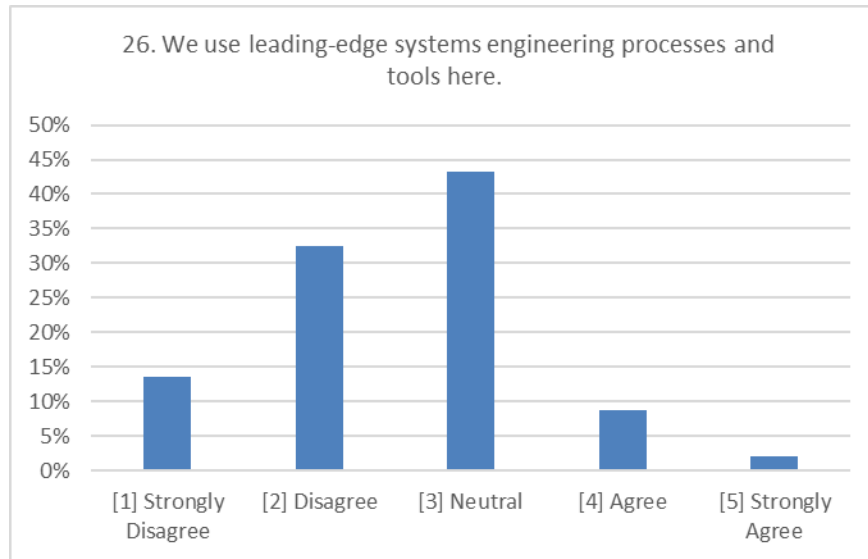


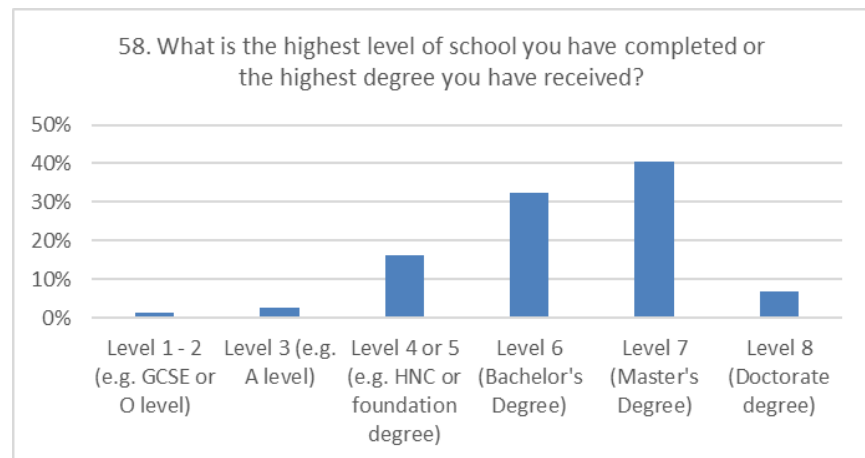
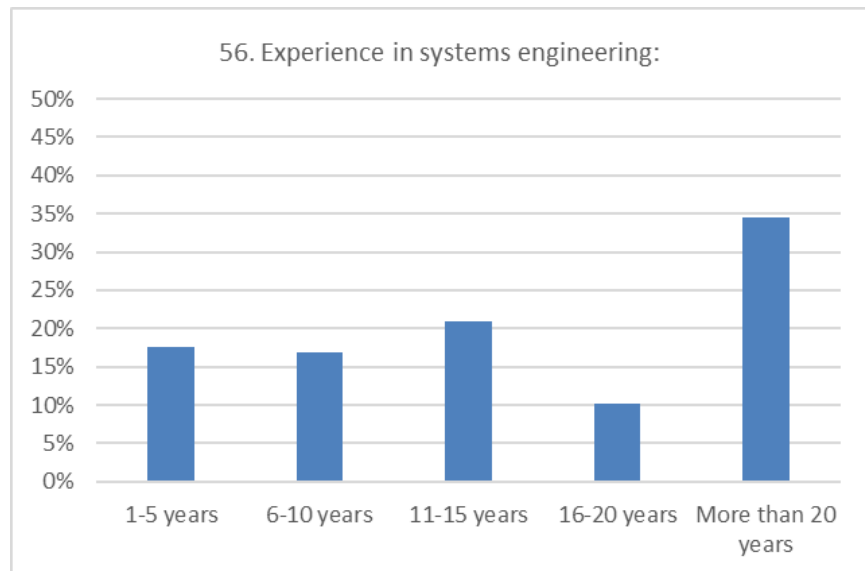
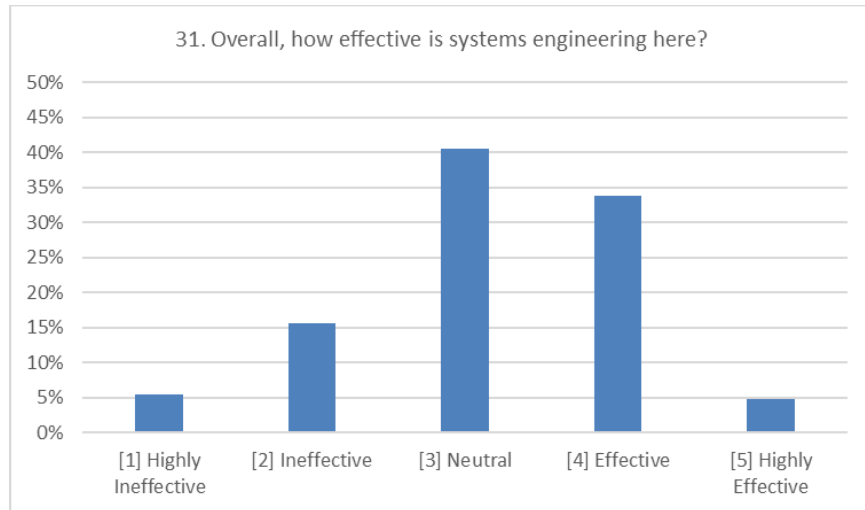


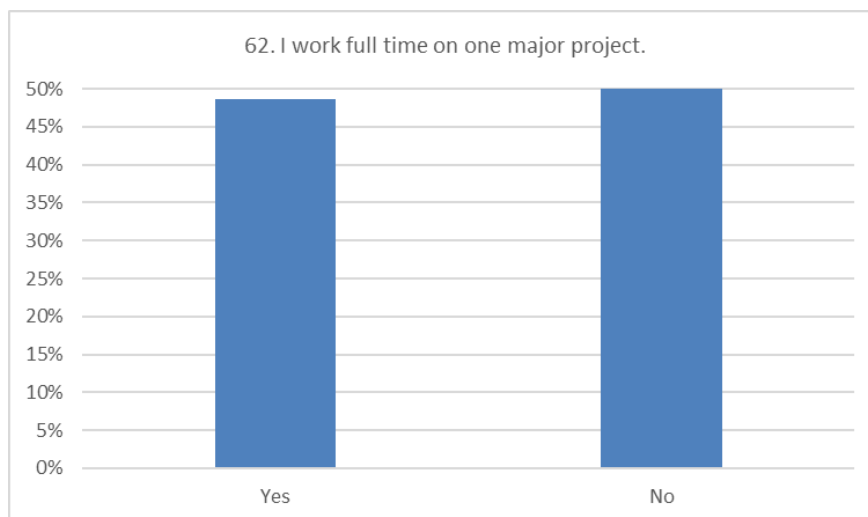
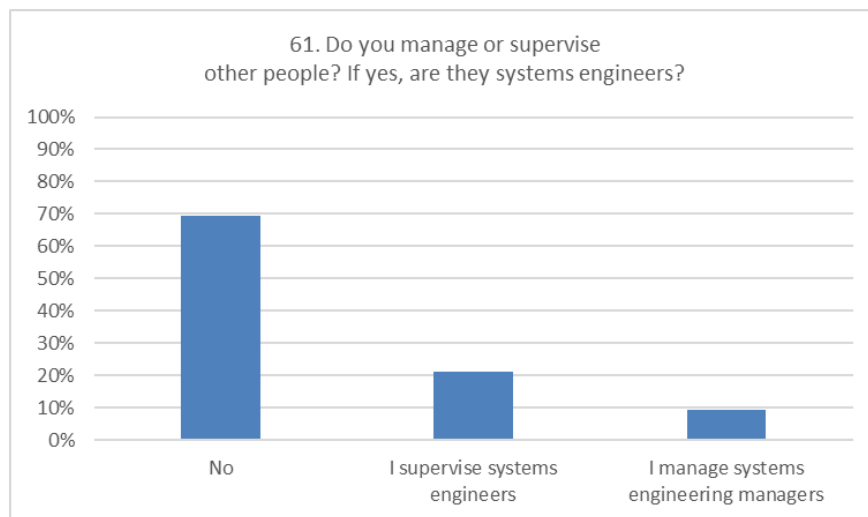
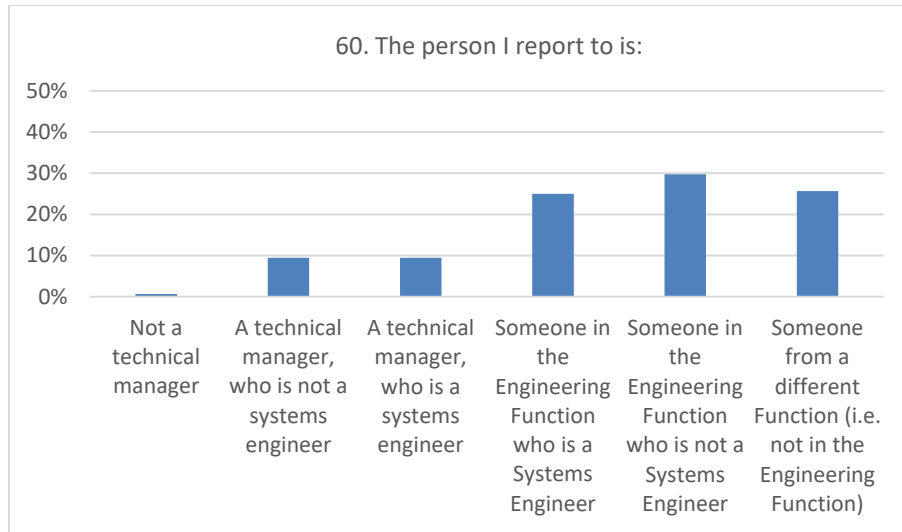


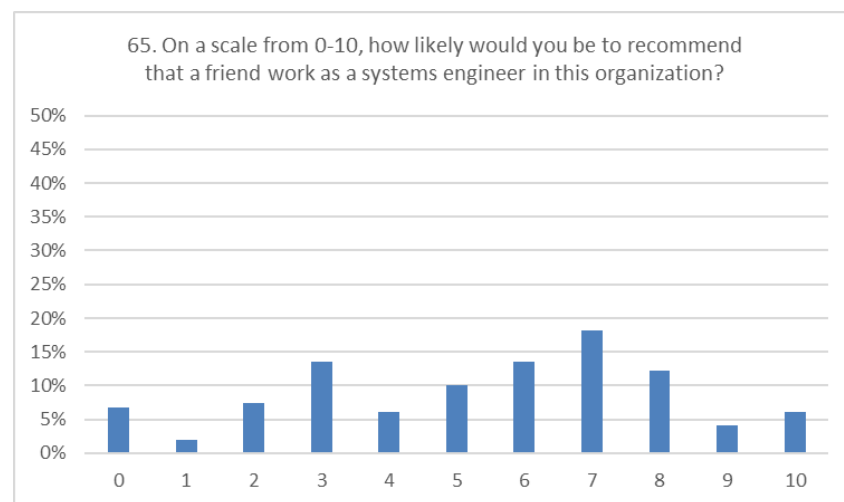
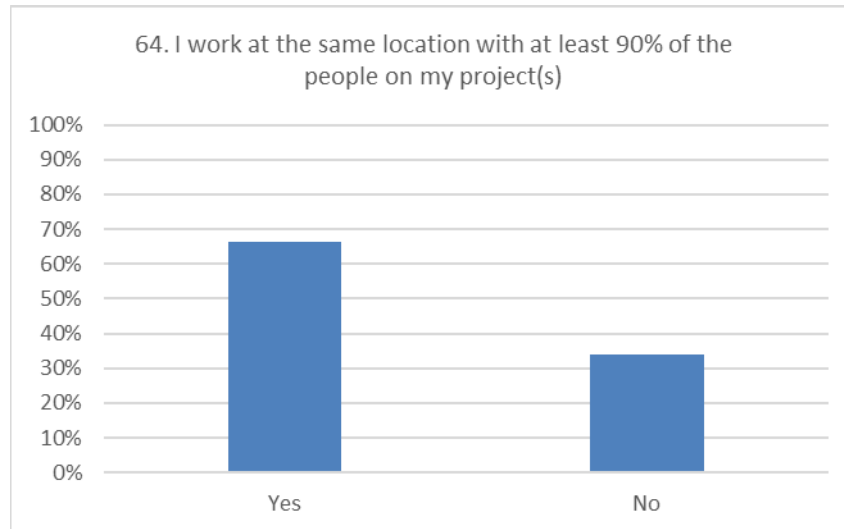












## APPENDIX F: RESULTS OF THE PEERS' SURVEY

---

The following are overall analysis across the full dataset for the survey of peers or companions. Note: Questions 1-6 are the OCAI tool for the CVF, and Questions 34-55 are the Qi Index, which are not repeated here since the organization-focused insights were shared in the Helix Findings Section.

