Mission Engineering Competencies

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Mission Engineering Competencies

Introduction

Mission engineering, or capabilities engineering, is the development and deployment of capabilities by applying an operational mission context to the relevant systems of systems (SoS) engaged in performing the mission. Mission engineering differs from traditional systems engineering because from the mission engineering perspective, the individual systems that comprise the capabilities are inherently flexible, functionally overlapping, multi-mission platforms supported by a complex backbone of information communication networks. The SoS approach has arisen in response to the needs for capabilities requiring multiple linked systems that are greater than the sum of the capabilities of the constituent parts.

The mission engineering competency model establishes the proficiencies for practitioners to perform effective mission engineering based on interviews and open source literature. We also detail the relationships between mission engineering, systems engineering, and system of systems engineering.

What is Mission Engineering?

There is no single definition of mission engineering, also referred to in the published literature as capability engineering. For example, the US Department of Defense (DoD) defines mission engineering as “the deliberate planning, analyzing, organizing, and integrating of current and emerging operational and system capabilities to achieve desired war fighting mission effects” [1]. A more general definition of mission engineering is the deliberate planning, analyzing, organizing, and integrating of current and emerging operational and system capabilities to achieve desired mission effects.

Mission engineering applies the mission context to complicated and complex system(s) of systems [2]. Most current systems engineering practices do not fully address the unique characteristics of mission engineering, addressing the end-to-end mission as the ‘system’ and extending further beyond data exchange between the individual systems for cross-cutting functions, controls, and trades across the systems.

Mission engineering differs from the established term of mission analysis in that the latter only addresses examination of current operational and system capabilities, and not the design and engineering to assure the mission. Mission engineering applies an operational mission context to the complex SoS. The SoS approach has arisen in the US Department of Defense (DoD) in response to needs for capabilities requiring multiple linked systems that are greater than the sum of the capabilities of the constituent parts. DoD differentiates mission engineering from traditional systems engineering because from the mission engineering perspective, the individual systems that comprise the military capability are inherently flexible, functionally overlapping, multi-mission platforms supported by a complex backbone of information communication networks. The same paradigm applies to infrastructure SoS such as electric power, communications, and transportation.

Research Task

The research identifies the critical skills required to successfully accomplish and shepherd mission engineering. Specific tasks are as follows:

- Identify competencies for mission engineering that are truly unique, showing where there is separation from the generally demanded systems engineering competencies
- Identify critical overlaps between mission engineering and systems engineering competencies
- Identify aspects of mission engineering that are general enough to be considered critical by the broader acquisition workforce, yet specific enough to support building interdisciplinary mission engineering knowledge and abilities
- Develop a mission engineering competency model that supports the engineering community but also provides input to each acquisition career field such as program management, and test & evaluation, unique to their responsibilities to support and manage mission engineering
- Conduct a gap analysis comparing current curricula against the competency requirements
- Provide recommendations on creating a mission-engineering curriculum, as well as modifying the applicable career fields' curricula to build interdisciplinary mission engineering knowledge and abilities.

The research is based on a mixed-methods approach, utilizing grounded theory to extract meaning from data collected in interviews as well as a traditional literature review. We interviewed practitioners to uncover the critical knowledge, skills, and abilities (KSAs) needed to perform effective mission engineering. In terms of the value delivered by mission engineers, we have identified aspects of mission engineering that are *unique* and relevant. We also interviewed thought leaders and other stakeholders in mission engineering related work to seek their expert opinions in order to understand the state of practice of mission engineering today and how mission engineering should evolve. This context is critical for understanding the competencies critical for successfully performing mission engineering. The mission engineering competency model development methodology is shown in Fig. 1.

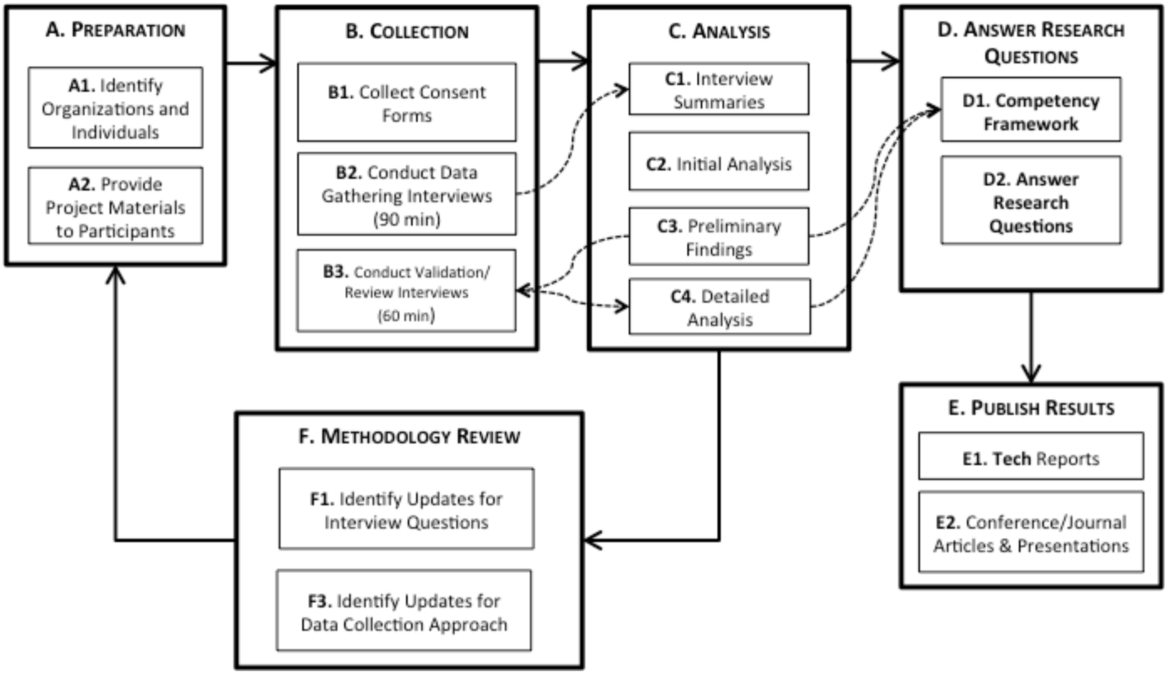

Fig. 1. Mission engineering competency model development methodology.

The interviewees were asked questions in three broad areas: their personal definition of mission and their organizations' definition of mission engineering; desired and actual competencies; and their vision for the future. Initial findings reflect the commonality across all organizations so that predominant organizations in the dataset do not dominant the results at the expense of insights provided by the set of organizations.

There is also a rich body of work in the open source literature over the last ten years describing mission engineering applications, methods, and tooling. This literature search includes both peer reviewed journals and conferences as well as education courses and in-house publications and training. Finally, we have provided recommendations for building mission engineering curricula to build interdisciplinary mission engineering knowledge and capabilities.

We conducted additional analysis shown in Fig. 2 to identify the possible gaps between the currently available curricula for mission engineering and the competency requirements.

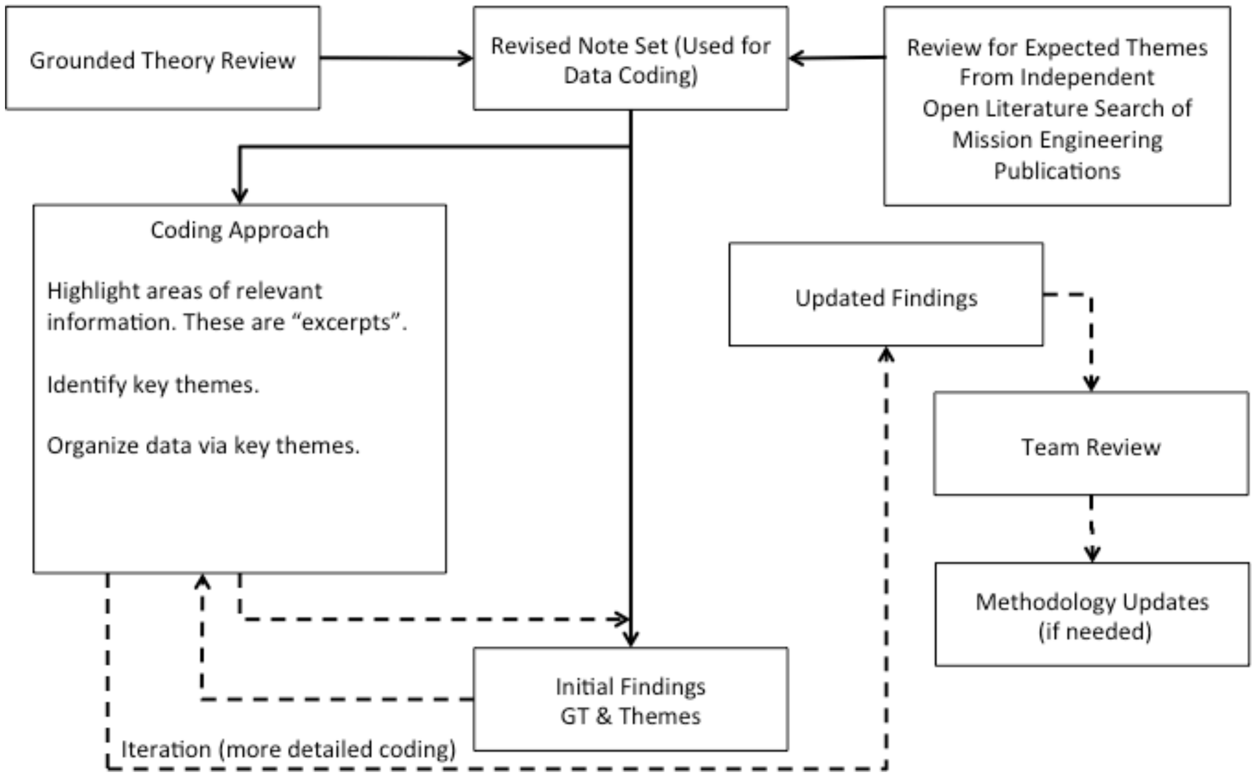

Fig. 2. Interview data analysis.

What is the Mission Engineering Competency Model?

A competency model lays out the knowledge, skills, abilities, and behaviors that are critical to a discipline. *The mission engineering competency model identifies the skills necessary to perform critical mission engineering activities across complicated and complex systems and systems of systems.* These activities include but are not limited to: mission analysis and synthesis, trade-off analyses, technology management, resource management, architecture development and modeling, mission modeling, addressing supporting capabilities such as communications and overarching mission functions, synchronization of testing, and individual system implementation. An effective competency model also reflects industry approaches and best practices.

Coding of the interview data used an iterative analysis based on grounded theory. The "bottom up" approach reflects the patterns seen in the data and this is paired with a "top down" approach from reviewing the literature independently researched to avoid confirmation bias. The multi-iteration effort involved "chunking" the codes in to main categories, development of sub-categories, and additional refinement. The flow of the coding using iterative analysis is shown in Fig. 3.

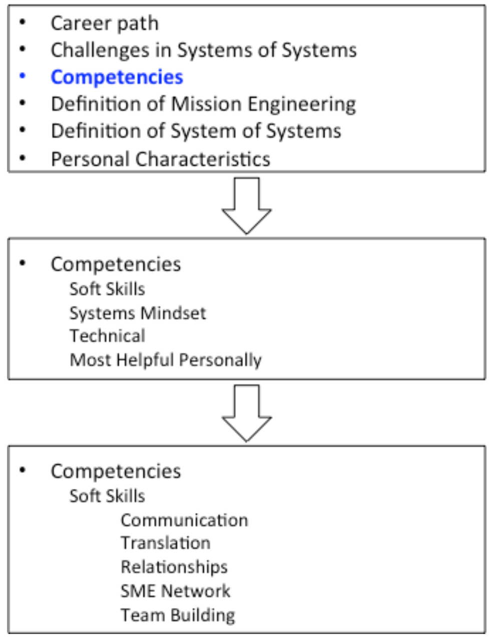

Fig. 3. Iterative analysis in the coding of interview data.

Initial Findings

There is a clear link in the interview data and open source literature between systems engineering and mission engineering, though not universal agreement on how the two are related. Interview responses about the distinctions are situational. The variations in responses, shown in Fig. 4, are ordered from most frequent to least frequent as follows:

- Mission engineering is systems engineering plus
- Mission engineering is system(s) of systems engineering
- Mission engineering is systems engineering
- Differences between mission engineering and systems engineering.

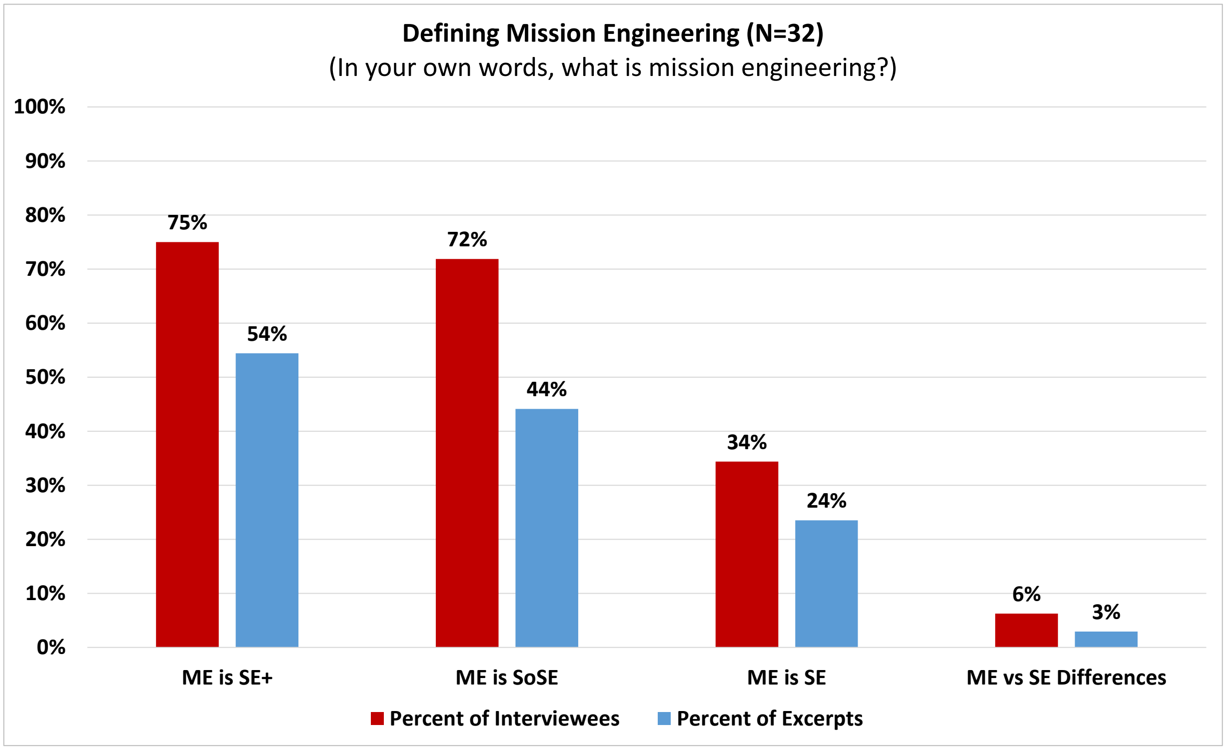

Fig. 4. Percentage of excerpts and interviewees based on their definition of mission engineering.

We also asked the participants in the study to provide us their perspectives on their respective organizations' definition and philosophy on mission engineering. Fig. 5 depicts the interview participants' perceptions and understanding of their organizations' definition and philosophy on mission engineering, which can be summarized as:

- A comparison between the interviewees own definitions as shown in Fig. 4 with their organizations' definitions of **"mission engineering is SoSE"** indicates that ***their philosophy is aligned with their organizations***
- The participants considered their organizations' **understanding of the operational context** as the main philosophy on mission engineering
- Fifteen percent of them said their organizations have no definition or philosophy, followed by some that indicated their organizations generate minimum effort to meet mission objectives
- A minimal amount of interview participants perceived their organizations as being confused with the different definitions, and some even considered mission engineering as out of their organizations' scope.

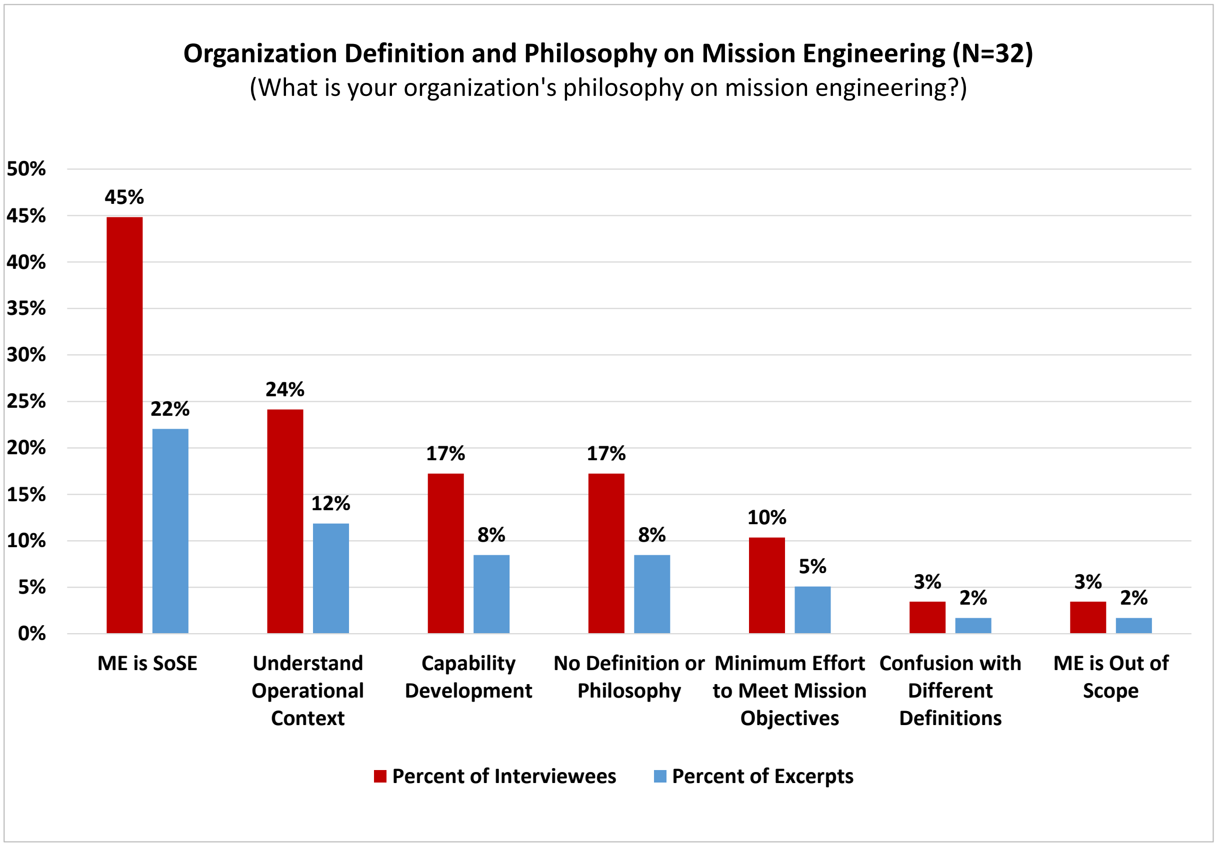

Fig. 5. Perspectives on the organization definition and philosophy on mission engineering.

Mission engineering incorporates finding the gaps in current capabilities; developing solution recommendations to find the operational shortfalls, called capability solution management; and processing the results for approval, execution, and implementation. Fig. 6 illustrates this approach to mission engineering activities that associates it and traditional systems engineering within the "V" model as time evolves [3].

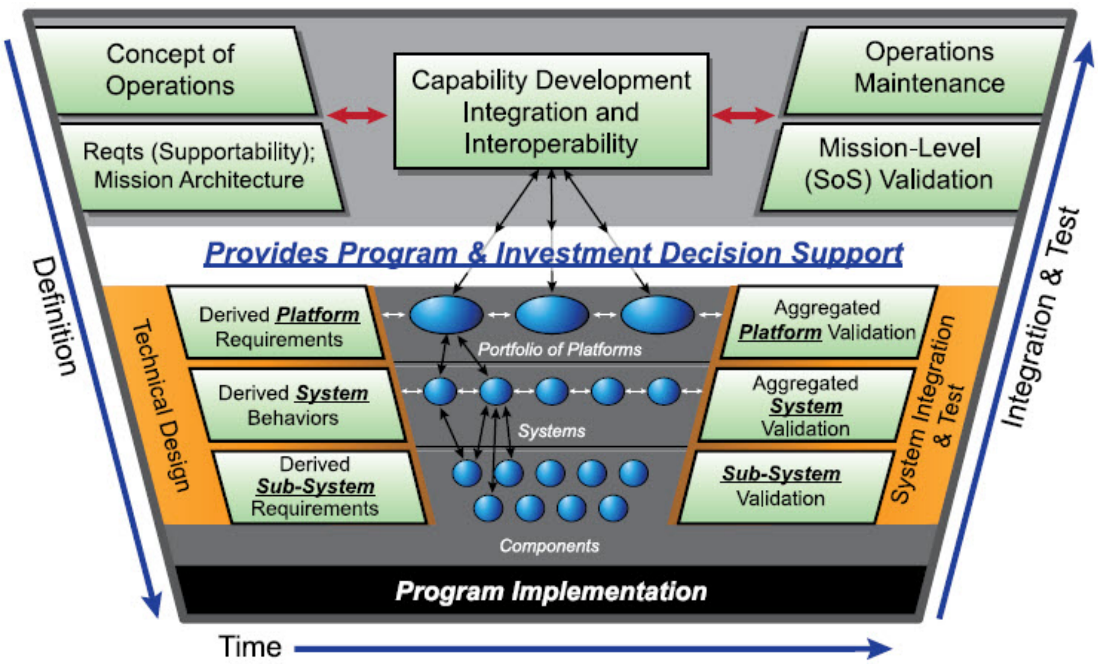

Fig. 6. Mission engineering within the systems engineering "V" model.

Before we show the initial mission engineering competency framework, we reference the Helix proficiency model of a systems engineer as a baseline in Fig. 7 [4].

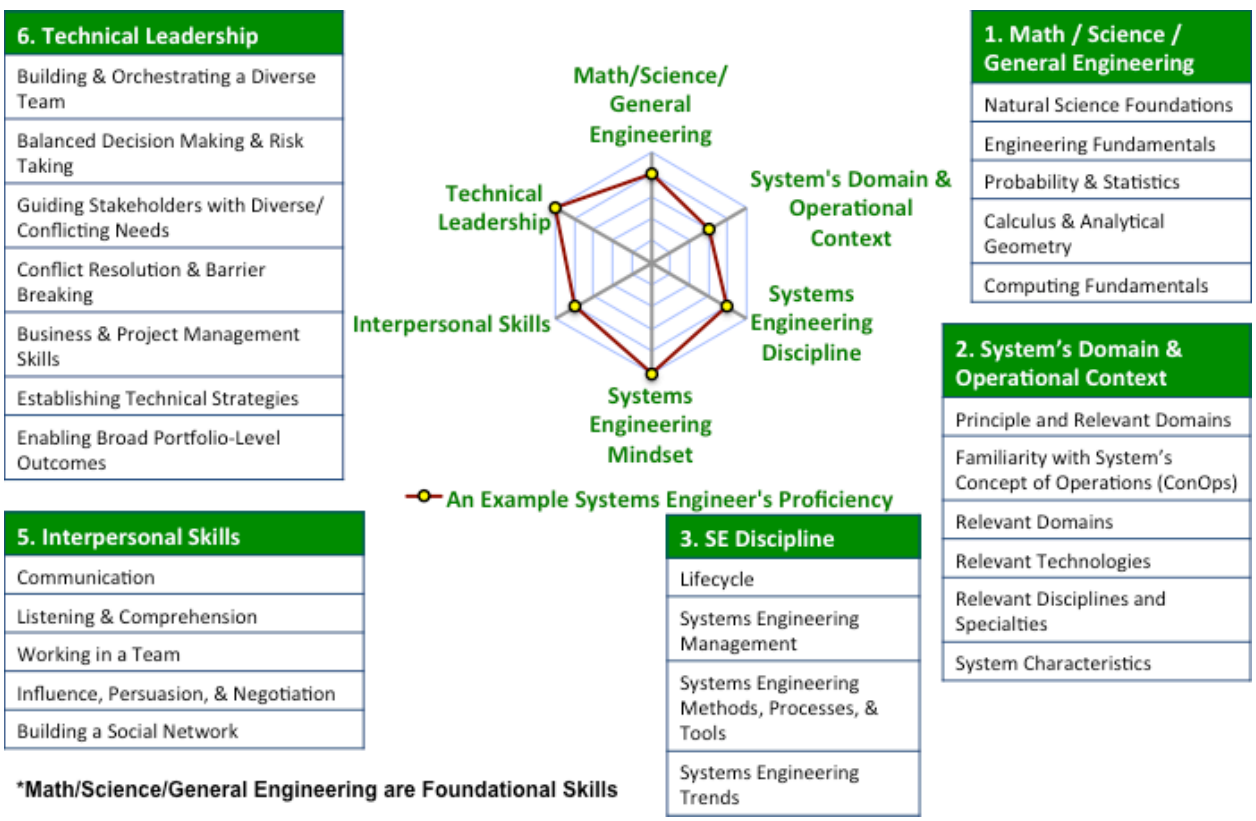

Fig. 7. Helix competency model of a systems engineer [4].

The mission engineering competency framework of areas and competencies is shown in Fig. 8. Specific competencies in the Helix model shown in Fig. 7 become dominant in mission engineering. An important distinction here is that the competency model in Fig. 8 is for mission engineering, not necessarily for the individual mission engineer. Interview data validates the concept that mission engineering, similar to systems engineering, is a "contact sport" requiring effective teams. We have consistently heard that effective mission engineering teams require members spanning both operational domain experiences and engineering domain skills. The sum total is rare in an individual mission engineer.

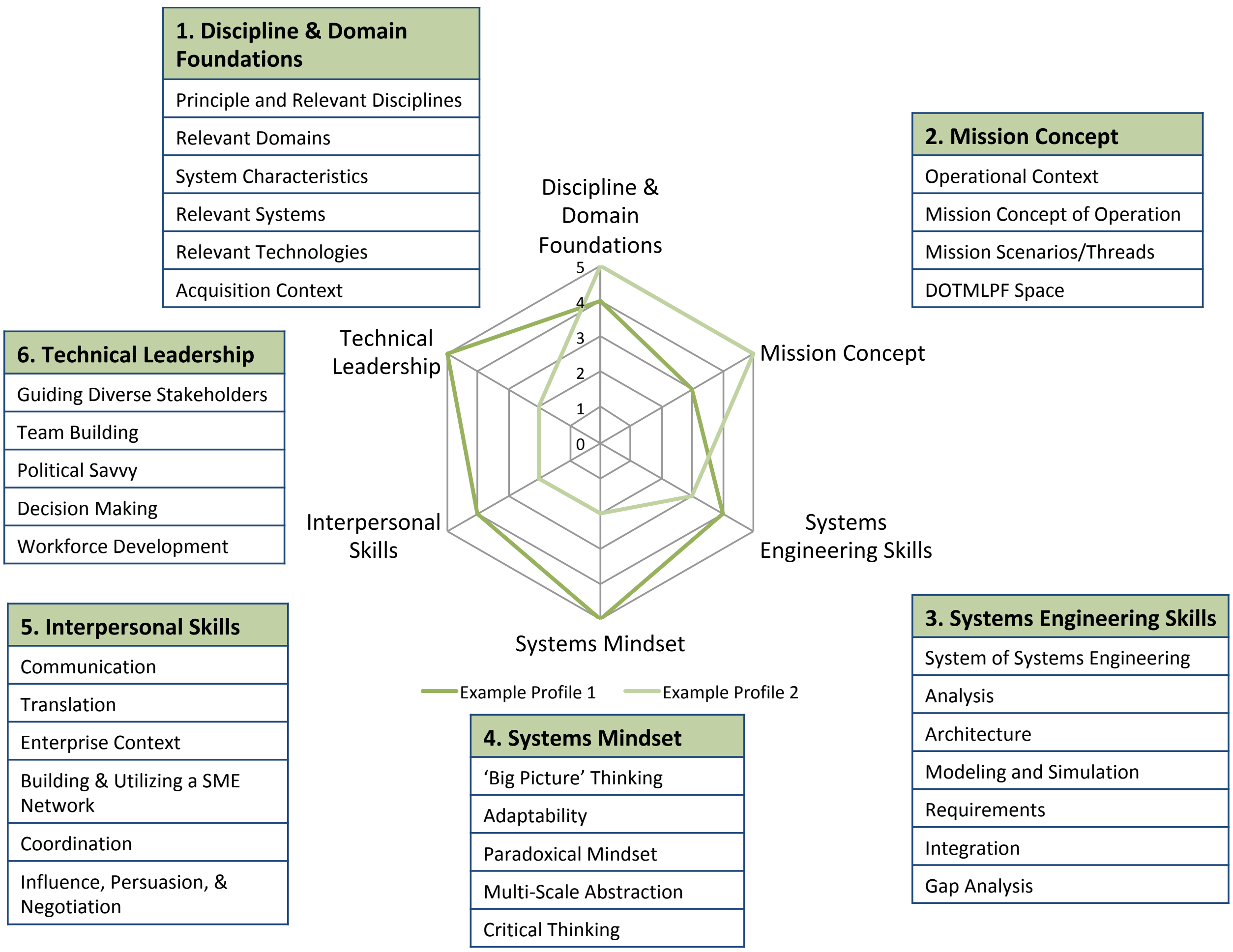

Fig. 8. Mission engineering competency framework.

The mission engineering competency framework has six areas, each with subordinate categories:

1. ***Discipline and Domain Foundations:*** This area focuses on the foundational understanding of the *systems* that will be required to support a given mission.
2. ***Mission Concept:*** This area focuses on an individual's ability to understand and work within the context of a given mission, including understanding the overall concept, scenarios, and relevant mission threads as well as understanding the factors that may influence the mission in addition to technology (doctrine, processes, training, etc.).
3. ***Systems Engineering Skills:*** Mission Engineering and Systems Engineering share critical overlaps (see Section 1). This area provides clarity on the specific systems engineering KSAs that are most critical for mission engineering.

4. ***Systems Mindset***: This area is analogous with the systems mindset in *Helix* (Hutchison et al. 2018) and includes the cognitive abilities around thinking holistically as well as being able to identify the right levels of detail and integrate these perspectives.
5. ***Interpersonal Skills***: This area includes the skills and behaviors associated with the ability to work effectively in a multi-team environment and to coordinate across the mission scope.
6. ***Technical leadership***: Skills and behaviors associated with the ability to guide a diverse team of experts toward a specific technical goal.

Research Findings on the Scope of Mission Engineering

The scope of mission engineering is analyzed from 1) the critical activities identified by mission engineers in interviews and 2) the critical systems engineering competencies they use.

Fig. 9 shows the interview responses analysis on the critical activities in mission engineering, which can be summarized as:

- Critical **mission-focus** activities begin first and foremost, with an **understanding of the mission** as the highest overall compared to other activities, indicated by the highest percentage of interview participants

- **Top technical activities** include the architecture, analysis, requirements, modeling and simulation, capability development, integration and interoperability, testing and evaluation, technical assessments, and composition – all of which are recognized as difficult in a complex mission environment

- Other **non-technical activities** include communication, workforce development, and uncertainty when dealing with mission engineering work

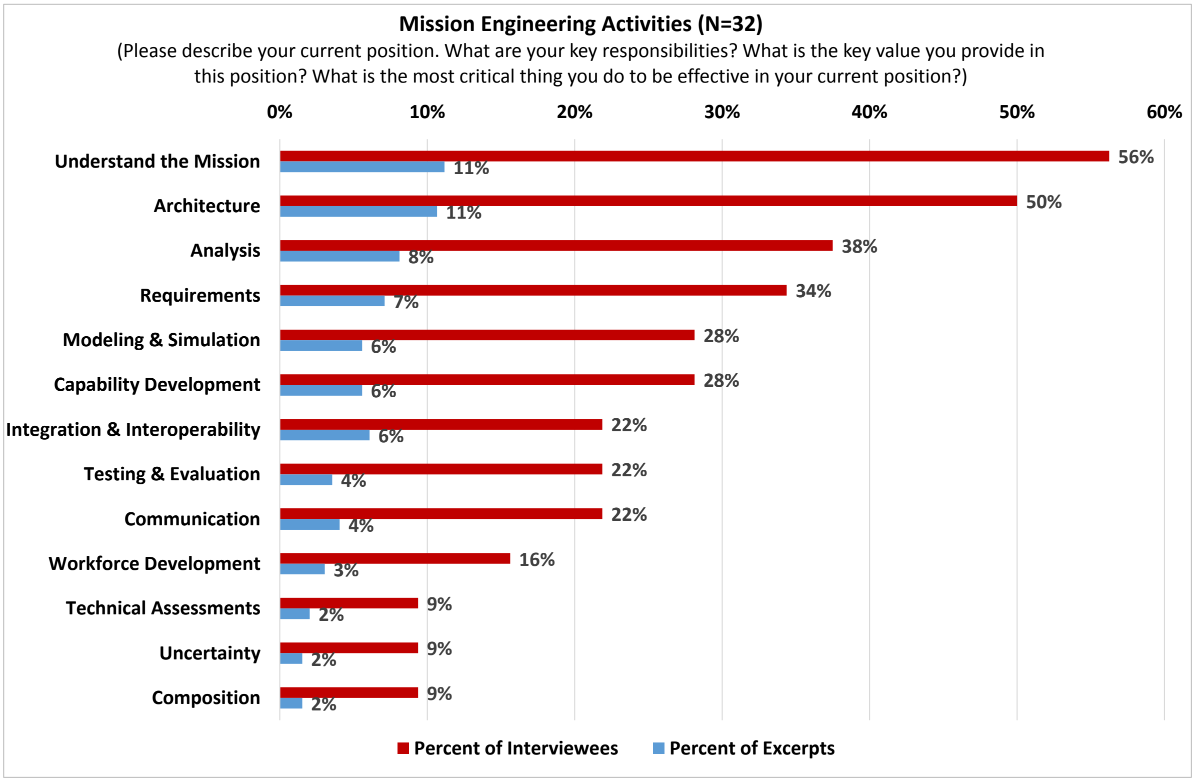

Fig. 9. Understand the mission, architecture, analysis, requirements, and modeling & simulation dominated the critical activities performed by mission engineers.

Fig. 10 shows the analysis of the interview responses to the question on the critical systems engineering competencies in mission engineering.

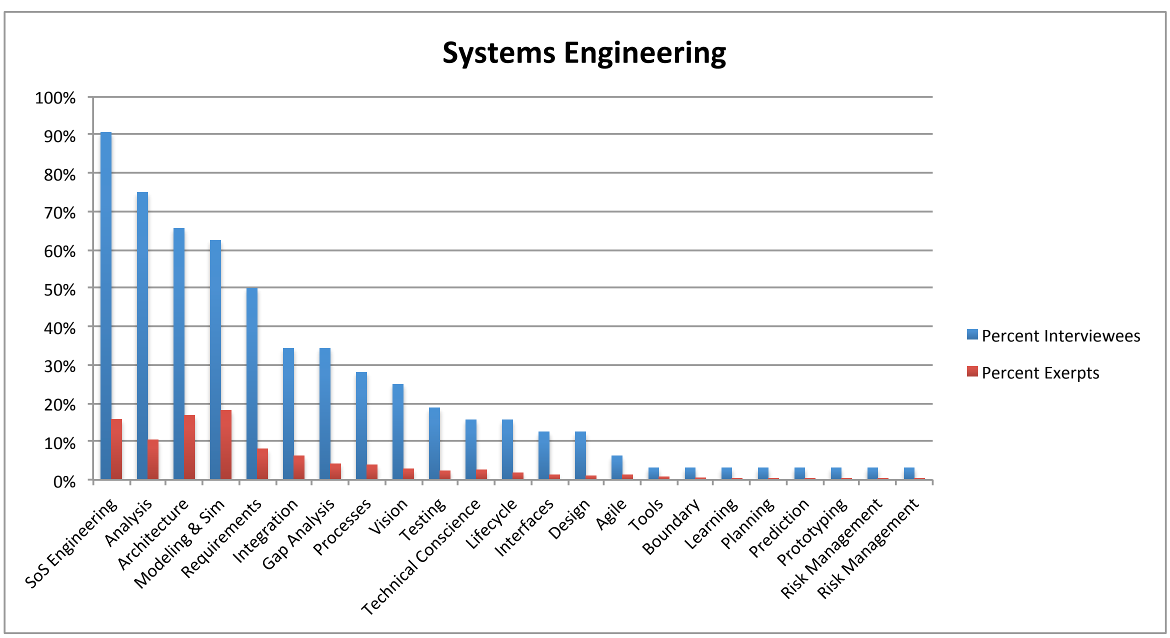

Fig. 10. Critical systems engineering competencies in mission engineering.

Because there were 22 individual competencies identified, to make cutoff determinations for systems engineering skills, the first metric was the percentage of interviewees who described a specific capability. For instance, while agile methods, critical tools, and prototyping were all described, they were each described by only a single individual in the sample, meaning it is reasonable to leave them out of the ME Competency Framework. This does not mean that these skills are unimportant but that perhaps they are more crucial in certain organizations or for a very specific mission.

Competencies included in the ME Competency Framework related to systems engineering included:

1. SoS Engineering
2. Analysis
3. Architecture
4. Modeling and Simulation
5. Requirements
6. Integration
7. Gap Analysis.

SoS engineering was the most commonly-cited skill (91% of interviewees and 16% of excerpts) and emerged in two ways: either individuals specifically cited SoS engineering as a critical skill or individuals cited "systems engineering" as a critical skill, but they had defined "mission" systems as SoS's and had stated that the SoS perspective was critical. Likewise, Analysis, Architecture, Modeling and Simulation, and Requirements were all heavily cited as important.

The cutoff for inclusion in the Systems Engineering area was competencies cited by at least 34% of the interviewees, which incorporated Integration and Gap Analysis.

However, it is important to note that the ME Competency Framework is intended to be tailored and, to that end, it is likely that the Systems Engineering area would be tailored to highlight crucial skills for certain types of systems, operational contexts, etc.

Critical Findings from Open Source Literature

The open source literature search identified three topics that are critical to achieving the desired capabilities in the context of real-world operations:

1. Non-determinism of real-world phenomena – the techniques and tools to perform mission analysis and engineering appear to be deterministic in nature [3] [5]; the real world is quite the opposite [6] [7].
2. Explicitly accounting for systems operational availability $A_o < 1$ – systems A_o in real world scenarios is rarely "1" A relevant example is the operational availability of the

integrated system of systems for Predator, Gray Eagle, and Reaper remotely piloted aircraft (RPA) operations [8].

3. Explicitly accounting for the human operators and commanders in the loops of the systems of systems – human beings require time to sense, think, interact, and decide that impacts the theoretical performance of systems of systems. Again, a relevant example is the PEST (political, economic, societal, and technological) factors on effectiveness of RPA operations [8]. A non-defense example is the landing of US Airways Flight 1549 in the Hudson River between New York City and New Jersey on January 15, 2009 after a bird strike resulted in the shutdown of both engines. Initial analysis of the NTSB replaying the flight on simulators indicated that the aircraft could have made an emergency landing back at LaGuardia Airport or at Teterboro Airport in New Jersey. The flight simulator scenarios did not account for the time for the aircrew to assess what happened, understand the state of their aircraft, and regain situational awareness. Factoring in the latency of the aircrew in the simulators gave the result that an emergency landing at LaGuardia or Teterboro was not viable.

Gaps in Systems Engineering Curricula for Effective Mission Engineering

A baseline for system engineering curricula at the graduate level is the Body of Knowledge and Curriculum to Advance Systems Engineering (BKCASE®) project: *Graduate Reference Curriculum for Systems Engineering (GRCSE®)* [9]. GRCSE is a set of recommendations for the development and implementation of a systems-centric professional master's degree program in systems engineering [10]. The systems engineering curriculum recommendations have limited coverage of system(s) of systems topics at the knowledge level of Bloom's taxonomy: 1) architecting approaches for SoS, socio-technical features of SoS, and capability engineering.

Summary

Mission engineering is the application of system(s) of systems engineering in an operational context. The research task and objectives identified the critical skills required to successfully accomplish and shepherd mission engineering. The initial competency model builds on grounded theory leveraging the Helix methodology on developing effective system engineers, using a combination of mission engineer interviews as informed by searching the open source literature. Interviews and open source literature covers 1) mission engineering definition and organizational support, 2) identification of competencies and gaps, and 3) future vision. Mission engineering overlaps systems engineering competencies with important differentiation in 1) governance, 2) foundational math/science/general engineering skills, 3) operational concepts, 4) interpersonal skills, 5) and leadership.

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