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The State of Systems Engineering Technical Practice versus Discipline: A Survey of INCOSE Chapter Attendees in North America

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Abstract. In 2017, the author initiated a Systems Engineering (SE) Fundamentals Research Project to assess the "current state" of SE practice versus the "should be state" of the discipline of SE. Peer level Engineering often question and challenge SE as a domain of Engineering due to a lack of codified concepts, principles, and practices despite having a body of knowledge.

This paper summarizes results of a series of research surveys concerning the "gap" between the state of SE practice versus the discipline of SE. Survey results represent "core samples" from INCOSE chapter meeting attendees at geographically dispersed locations in North America. Survey participants included INCOSE Systems Engineering Professionals (SEPs) i.e., INCOSE Acquisition SEPs (ASEPs), Certified SEPs (CSEPs), Expert SEPs (ESEPs), Non-SEP members, and non-members. Project survey results correlate with Wasson's (2018) personal assessment over 30 years and serve as a frame of reference for INCOSE's Future of SE (FuSE) Team for instituting corrective actions to achieve its Vision 2025.

The paper concludes with findings and recommended *corrective actions* that industry, government, academia, professional societies, and standards organizations collectively need to reestablish SE technical core competency as a cornerstone of the discipline of SE. Then, in combination with SE Management and processes, achieve a proper balance between the two (Ryschkewitsch, et al, 2009).

Introduction

Wasson (2018) presented a technical paper at the INCOSE IS2018 in Washington, DC tracing the origins of poor project technical, cost, and schedule performance to an outdated 1950's Systems Management "groupthink" paradigm. The paper illustrated how the focus on SE technical competency as the "core" of an emerging discipline of Engineering shifted to an imbalanced focus on Systems Management and processes. The intent was to correct a workplace managerial competence issue to regain *authoritative control* over Engineering "knowledge workers" (Drucker, 1974, pp. 170 - 179), who were considered "lively and unruly" (Johnson, 2002, 2013). SEs morphed into interdisciplinary process "coordinators and communicators" among Engineering disciplines. After 60+ years, now is the time for the SE Community of Practice (CoP) to shift and correct this outdated SE paradigm and demonstrate to the larger Engineering community that SE is based on true Engineering discipline and rigor that drive its state of practice, not vice versa.

Today, SE is exemplified by: (1) everyone in the workplace being labeled an SE whether qualified or not, (2) philosophical studies of origins to system sciences, (3) mistitled textbook claims, (4) courses taught by instructors with little or no actual industry experience, and (5) certification exams based on process handbooks.

At INCOSE's 2019 International Workshop (IW2019), the Future of Systems Engineering (FuSE) team conducted a workshop to explore the current state of SE, challenges, and what the future state of SE should be. Draft findings from the FuSE Workshop included a key section titled "What's stopping us?" that included the following points:

- "SE and systems science lack credibility as a discipline in academia.
- Leaders of businesses in many sectors do not believe that SE adds value.
- There is a general perception that SE is not essential.
- No sense of urgency or importance in SE community." (IW2019)

This paper validates the gap that exists between the "current" state of SE practice versus the discipline of SE. Hopefully, the results of this survey will motivate *change agents (Figure 9)* to inspire a shift in this outdated SE paradigm and restore Engineering discipline to SE worthy of the respect of its peers.

Statement of the Problem

Engineering projects continue to exhibit technical, cost, and schedule performance issues that trace back to a variety of factors that include interdisciplinary contributions from Systems Engineering. Specifically, issues traceable to SE concepts, principles, and practices; problem-solving and solution-development strategies, approaches, and methods; decision-making process efficiencies and effectiveness; SE education and training; and so forth.

Literature Search

Although SE core competency is often discussed as an abstract concept, limited work has been done to address the implications of ignoring it over the past 60+ years. Papers written by the authors listed below highlight perceptions of SE, discuss what occurs when an imbalance exists between SE technical and management competency when one dominates the other, and misperceptions of SE as a *professional practice* versus the discipline of SE.

- Cowper and Smith (2003)
- Dixit and Valerdi (2007)
- Emes, Smith, and Cowper (2005)
- Gelosh, Heisey, Snoderly, and Nidiffer (2018)
- Kasser, Hitchins, and Huynh (2009)
- Ryschkewitsch, Schaible, and Larson (2009)
- Slegers, Kadish, Payton, Thomas, Griffin, and Dumbacher, (2012)
- Wasson (2010, 2012, 2016, 2018)
- Whitcomb, White, Kahn, Grambow, Velez, and Delgado (2017)

SE Practice versus the Discipline of SE

Central to this paper's discussion is: *what is the frame of reference that characterizes Systems Engineering discipline as a competency frame of reference to enable assessment of its everyday practice?*

At a *minimum*, the strength and durability of a discipline-based technical competency requires:

1. Scholarship.
2. A formal, rigorous education in a field of study characterized by a systematic body of knowledge governed by a set of laws, concepts, principles, and practices and verification by an educational authority such as the American Board of Engineering and Technology (ABET).
3. A lifelong career of professional and ethical conduct and accomplishment demonstrated by the individuals claiming or designated to exhibit a core competency.
4. Certification by a professional decision authority authenticating the competency.

A word of caution. Whereas Engineering disciplines such as EE, ME, et al are domains or branches – i.e., "stovepipes" - of Engineering, Systems Engineering as an *interdiscipline* is uniquely different. SE is built on an Engineering foundation with horizontal linkages to EE, ME, et al as well as other domains such as Economics, Statistics, humanities, et al. In the past 20 years, SE has evolved through the efforts of the International Council on Systems Engineering.

Engineering disciplines evolve slowly and establish their roots in codified concepts, principles, practices, laws, and standards to guide, preserve, and ensure the scope and integrity of its conduct. Where these conditions are lacking, a casual, *ad hoc* mindset evolves. The problem has been exacerbated over the past 60+ years with the promulgation of SE Management and processes at the expense of SE core technical competency.

Based on the author's experience over 47 years in working with many companies and government agencies, the state of SE practice is often *casual* rather than *rigorous* despite the progress that has been made. As one of the most abused titles in Engineering, unwitting enterprise managers "knight" any engineer who exhibits "systems thinking" as an SE (Wasson, 2018).

Unlike EE, ME, and other Engineering disciplines, so-called SE in today's industry and government workplaces often consist of isolated fragments of the discipline of SE such as requirements identification, analysis, and traceability and system architecting.

Engineers perform the way they have been educated and trained or the lack thereof. As a result, implementation of SE in many workplaces exists in the form of a traditional, educational classroom paradigm referred to as the Engineering Design Process (EDP). The EDP is an *ad hoc endless loop*, activity-based, derivative of the Scientific Method that is intended for scientific inquiry and investigation, not System Engineering Problem-Solving and Solution Development. In Engineering terms, EDP is nothing more than an endless loop of Specify-Design-Build-Test-Fix (SDBTF) Paradigm (Wasson, 2006, 2016) of activities and tweaking that never seem to come to completion.

Given this background, *how do we establish a frame of reference for assessing the "gap" between the State of SE practice versus the discipline of SE*? The frame of reference exists in the form of two (2) SE textbooks by Wasson (2016) and Blanchard and Fabrycky (2011).

- Wasson presents a comprehensive codification of SE concepts, principles, and practices that have been tempered by years of industry experience.
- Blanchard and Fabrycky co-authored five editions of a comprehensive textbook integrating Systems Engineering and Systems Analysis.

Formulation of the SE Foundations Research Project

Based on the preceding discussion, the SE Fundamentals Research Project probed key foundational "check points" in SE practice to assess *how SEs think*, which influences their performance. It is the author's position that a professional discipline is characterized by a set of cornerstone laws, concepts, principles, and practices as well as *rigor* that should be indelibly marked in one's mind. Illustrative examples include: EE – Ohm's Law, Physics – Newton's Laws of Motion, et al without aid of external resources. So, *the question becomes what are those analogues in SE*?

Research Objectives

The overarching project objective was to collect, analyze, assess, and understand objective evidence from survey participants to determine how the typical SEs "thinks." Most importantly, was the need to "draw out" expressions in responses that reveal their SE knowledge and experiences without recitation of defacto definitions and "talking points" created by industry, government, professional societies, and standards organizations.

Research Question

From an Engineering discipline perspective, the key research question is:

> *Does a "gap" exist between the state of Systems Engineering practice relative to the current state of discipline of SE* ?

System Engineering performance in the workplace occurs in two forms: (1) what enterprises, executives, projects, and SEs *claim* or *believe* they do – e.g., follow organizational standard processes (OSPs) - versus (2) SE behavioral actions that reveal *how SEs think* within their "inner core." Theoretically, if SEs have been formally educated to be technically competent in the discipline of SE, then their behavioral responses should closely correlate with its concepts, principles, and practices, especially since behavioral actions reflect *how* an individual or team "thinks" and makes decisions.

Research Data Survey Method

One of the challenges of a survey of this type is being able to encourage a typical SE to *freely reveal* their inner thoughts and allow them to emerge, which translates into *how* they instinctively perform on technical projects. More specifically, when posed a question purposely constrained by response time, what are an SE's primary reactionary thoughts that emerge from their "inner core". Several interview tool options were available:

1. **On-Site Personal interviews** when conducted in a personal, "one-on-one" setting are ideal but impractical in terms of geography and time efficiency.
2. **Phone interviews** when conducted in a personal, "one-on-one" setting are generally good but impractical from a coordination perspective and being able to observe the interviewee's body language.
3. **On-line surveys** allow the candidate to take as much a time as they need to "lookup" and "word-smith" responses from professional, standards, et al organizations.
4. **Group surveys** offer the opportunity to proctor the survey and *preclude* survey participants from: (1) researching responses on the Internet via computers or cellphones or (2) collaborating with other respondents.

Based on an analysis of these options, group surveys emerged as the *optimal* solution. This lead to the next question: *who, what, when, where, and how will the group surveys be conducted*? Since the survey was intended to sample SE populations of industry, government, academia, et al, INCOSE Chapter meetings in North America provided a natural forum for conducting the surveys. This lead to a final decision on project survey requirements and constraints.

Project Survey Requirements and Constraints

The administration, conduct, and control of the survey required definition of several constraints:

1. Constraint #1 – Conduct the pre-coordinated survey real-time at a scheduled INCOSE Chapter meeting.
2. Constraint #2 – Complete the survey within 20 minutes to minimize disruption to the meeting agenda.
3. Constrain #3 – Limit the survey to one (1) page including space for respondents to answer questions.
4. Constraint #4 – "Closed book" – i.e., resources - to preclude collaboration with and influence by others or looking up answers via computer or cell phone.
5. Constraint #5 – Administer the survey via an administrator who will be the only one with *a priori* knowledge of the questions.
6. Constraint #6 –*Respondents answer survey questions … in their own words*. Avoid typical survey flaws that ask respondents to select answers to abstract questions using a predetermined set of responses or quantify the level of agreement/disagreement on a scale of 1 (Low) to 5 (Highest) that precludes their "inner thoughts" from emerging.

Regarding Constraint #6, research surveys are often created to facilitate analysis and data reduction by the researcher. Yet, the surveys fail to understand *how* the respondent *actually thinks*. As a result, survey participants often find themselves attempting to fit "a square peg (their thinking) into a round hole" (pre-determined survey response options).

Project Survey Methodology

The survey methodology consisted of the following steps:

1. Identify potential INCOSE chapter candidates that are geographically distributed in North America – US and Canada.
2. Obtain INCOSE agreement with each chapter to conduct the survey.
3. Plan, coordinate, and conduct the survey.
4. Identify a Point of Contact (POC) – e.g., officer or members - from a chapter's INCOSE membership to serve as the survey administrator.
5. Conduct the survey.
6. Enter, aggregate, and process the survey data form results.
7. Analyze and assess the survey data results based on an authoritative frame of reference.
8. Develop research findings relative to survey overarching objective.
9. Develop recommendations and follow-on research.

Project Survey Participants

The project consisted of two phases: (1) direct email with INCOSE Chapter Presidents and (2) a solicitation for participation via an INCOSE America's Sector monthly conference call.

Initially, nine (9) INCOSE chapter presidents were contacted directly via email inviting their chapter's participation in the survey. Of those:

- Four (4) INCOSE Chapters *chose to* participate.
- Five (5) INCOSE Chapters *chose not* to participate via no response:
    - One (1) large chapter inquired if the chapter data would be made public; the response was *No*, data would be entered into an aggregate data set and summarized for reporting. The chapter president did not respond to two follow-up emails.
    - One (1) chapter indicated their leadership was in a state of transition and did not respond to follow-up.

During the IS2018 in Washington, DC, the INCOSE America's Sector Director requested that the researcher participate in a Global Meet video conference on August 22, 2018 when more chapter presidents would be accessible. Of the 41 INCOSE chapters in North America – US and Canada - 17 INCOSE Chapter presidents and/or their representatives participated in the America's Sector meeting.

- One (1) INCOSE Chapter President expressed interest during the meeting and subsequently chose to participate in the survey.
- Two (2) INCOSE Chapters had already participated in the survey.
- 14 INCOSE Chapters were *non-responsive*.

Survey Form

The structure of the survey form consisted of two key data areas: (1) a participant profile area and (2) survey questions. To understand the context of participant responses to survey questions, participants were asked to fill out a brief profile concerning education – fields of study, degrees, university and corporate SE courses; INCOSE membership and certifications; years since graduation and as an SE, et al. Survey participants were allowed 5 minutes to complete the profile.

Formulation and development of the SE Foundations Research Project survey questions required a trade-off between the number of questions and reasonable time allocations to answer each question. Due to the 20-minute total time limit constraint, the challenge became: *From a Pareto priority perspective, what is the minimum set of questions that will fit within the allowable 15-minute timeframe to serve as assessment indicators of the SE technical competency of respondents*?

Surveys often focus on Yes/No questions or *subjective* 1 (Lowest) – 5 (Highest) value scale opinions such as "how would you rate …" based on a "brainstorming" exercise. A true assessment of the SE technical foundation requires *objective* insights into *how SEs think* under time constrained conditions. A list of essential SE competency questions was developed and prioritized. Using a nominal 2.5 minutes response time, the 15-minute time constraint allowed the six key questions:

1. What is Engineering?
2. What is System Engineering?
3. What is a System?
4. What is a Capability?
5. What is the underlying concept of SE?
6. Graphically sketch and annotate the SE Process.

The questions above are not random, philosophical ideas. The questions represent the author's 47 years of "hands on" engineering experience in medium to large enterprises and project level technical and managerial roles in industry and government. When *leading* small to large, complex projects confronted with challenging resource constraints, you need SEs and engineers who are well-grounded in these concepts. Your experiences may be different based on the sizes and complexities of your projects.

In the author's opinion, the focal points of these questions represent the cornerstones on which the discipline of SE is founded and all other SE concepts emanate. Examples include: stakeholder identification and analysis; multi-level requirements identification, analysis, and specification; system architecting; multi-level system design; system analysis, modeling, and optimization; lifecycle cost analysis; technical risk management; et al. As cornerstones, answers to these questions, their component attributes, and the ramifications drive how an SE thinks and makes decisions. From the author's perspective, the ability to answer these questions as a Systems Thinker is a *hallmark* of a technically competent SE.

Once the survey questions were identified, the challenge became: *what assessment criteria should be used to evaluate and assess survey participant responses*. To facilitate the assessment scoring, competency level labels such as Level 1, Level 2, etc. by the author and others – were combined with descriptive labels from the INCOSE SE Competency Framework (2018) - i.e., Level 1 *Awareness*, Level 2 *Supervised Practitioner*, Level 3 *Practitioner*, Level 4 *Lead Practitioner*, and Level 5 *Expert*. To deal with the probability of survey responses being a boundary less continuum, the survey required establishment of more technically *objective* criteria for assessing participant responses. As a result, the following assessment boundary conditions were established:

- Level 1 Awareness – Expresses general familiarity with the focal point concept of a question.
- Level 2 Supervised Practitioner – Expresses an understanding of the key criteria of the concept.
- Level 3 Practitioner – Expresses an understanding of "how to" implement the concept without supervision.
- Level 4 Lead Practitioner – Expresses: (1) a competent understanding of Level 3 SE technical criteria and the nuances and trade-offs of those factors in making decisions and (2) ability to integrate and troubleshoot performance issues in a project environment.
- Level 5 Expert – Expresses proven mastery of the SE body of knowledge including its concepts, principles, and practices across highly complex projects.

One of the nuances that emerged from the assessments was the need to delineate sublevels within a given competency level. For example, some upper Level 2 responses may not have met the Level 3 criteria but deserved recognition for having more than a basic Level 2 criteria understanding. As a result, x.5 competency levels were added – i.e., 0.5, 1.5, and 2.5. Additionally, when responses were assessed, the participants' profile credentials were not visible.

Now that we have established the basis and context for the survey, let's explore the results.

Survey Demographics and Results

Survey results from participating chapters were collected, entered as records into an aggregate relational database, and serialized for analysis. To understand the survey responses, we need to understand the professional qualifications of the survey participants. Table 1 provides a summary of key survey participant demographics.

Table 1: Key Survey Participant Demographics

Survey Participants	**Education**
• 41 – No. of INCOSE Chapters in US & Canada (Okey, 2019) • 5 – INCOSE chapters particioated in - survey • 73 – INCOSE Members consisting of: ➢ 1 – ASEP ➢ 25 – CSEPs ➢ 6 – ESEPs ➢ 41 – Non-SEPs • 16 – Non-members including one (1) former INCOSE member	• 68 - Earned BS/BA degrees • 40 - Earned MS degrees • 12 - Earned PhD. Degrees • 2 – No degrees specified
Professional Career	**INCOSE Member Participants**
• Years since undergraduate school ➢ Range - 4 years to 60 years ➢ Mean – 32.8 years • Years as an SE ➢ Range – 0 to 30 years ➢ Mean – 6.8 years	• Membership Longevity ○ Range – 1.5 years to 30 years ○ Mean – 10.4 years

Survey participants represent a diverse set of educational fields of study and degrees – e.g., BS/BA/B. Eng., MS, and PhD. Table 2 provides a summary listing.

Table 2: Survey participant educational fields of study and degrees.

BS/BA Degrees	Qty.	MS Degrees	Qty.	PhD. Degrees	Qty.
Engineering	2	Engineering	2		
Engineering - Aerospace	8	Engineering - Aerospace	4		
		Engineering - Aero/SE	1		
Engineering - Chemical	2				
Engineering - Computer	3	Engineering - Computer	1	Engineering - Computer	1
Engineering - Electrical	22	Engineering - Electrical	3	Engineering - Electrical	1
Engineering - EE/Minor Biology	1				
				Engineering - Electrical Systems	1

BS/BA Degrees	Qty.	MS Degrees	Qty.	PhD. Degrees	Qty.
				Engineering - ISE	1
		Engineering – Management	1		
Engineering - Mechanical	7	Engineering - Mechanical	4	Engineering - Mechanical	2
		Engineering - Systems	6	Engineering - Systems	1
EF					
Physics	2				
Physics/Math	1	Physics/Math	1	Physics - Atomic Quantum	1
Physics/EE	1				
Math	2				
Computer Science	2	Computer Science	1		
Computer Science/Math	1				
Software	1	Project Mgt. – SW Dev.	1		
		Systems Science	1		
		MBA	4		
		MIS/MBA	1		
		Space Studies	1		
		Strategic/Intel	1		
Biology/English	1				
Business	1				
History	1				
MSCI	1				
Oceanography	1	Oceanography/Computer Engineering	1		
		CSCI	1		
		SCI	1		
		Telecommunications	1		
Yes - Unspecified	6	Yes - Unspecified	14	Yes - Unspecified	1
Totals	**68**		**40**		**12**

Survey Question 1: What is Engineering?

Since SE is built on an Engineering foundation, every SE should have a fundamental understanding of what Engineering is and the outcome(s) it is intended to accomplish.

Few, if any, undergraduate Engineering Programs introduce students to the definition of Engineering. Universities create "preparatory" courses for incoming students such as freshmen orientations that introduce *how to study*, *how to adapt* to their new surroundings, and so forth. Yet, students typically spend 4 years earning an Engineering degree and may never learn the established definition of Engineering. In many cases, instructors are often unfamiliar with the definition. If you are going to claim to be a professional with a competency in Engineering and SE, learn the definition of Engineering! That cornerstone coupled with similar definitions for specific Engineering disciplines drives holistic decision-making throughout a career.

There are numerous definitions of Engineering in various publications. The Accreditation Board for Engineering and Technology (ABET), which accredits Engineering Programs in the US and internationally, serves as an authoritative source for defining Engineering via an obscure reference in Prados' (2007):

- **Engineering** "The profession in which … knowledge of the mathematical and natural sciences gained by study, experience, and practice … is applied with judgment … to develop ways to utilize economically the materials and forces of nature …for the benefit of mankind" (Prados, 2007, p. 108).

  Note: "…" pauses above were inserted by the author to isolate key phrases of the definition to serve as "completeness" criteria for assessing participant responses.

Survey Results – What Is Engineering?

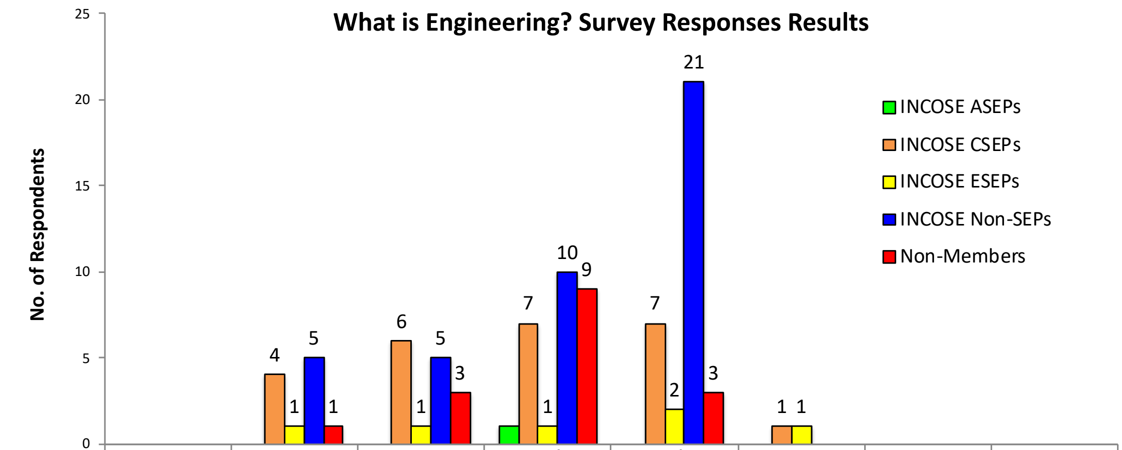
Table 3 provides illustrative examples of types of survey participant responses to Question 3.

Table 3: Example Responses – What is Engineering? survey question.

INCOSE Competency Descriptor	Competency Level	**What is Engineering?** Assessment of Example Survey Responses
Awareness	Level 1	The practice of making an assembly more efficient.
	Level 1.5	Design, testing, functions - mathematical, simulation process.
Supervised Practitioner	Level 2	Solving problems through application of science and logic.
	Level 2.5	Discipline that involves math, science, and people skills that is used to produce useful items for humans.
Practitioner	Level 3	Practical application of scientific knowledge and techniques in a fashion that brings value toward solving challenges for humanity or the environment.

Figure 1 provides a frequency distribution of survey participant responses to Question 1 *What is Engineering*? The SE technical competency levels ranged from a Level 1 Awareness to a Level 3 Practitioner technical competency. One (1) INCOSE ESEP and one (1) CSEP qualified as Level 3

Practitioners. The Mean of the distribution was **2.14** on a 5.0 (highest) scale with a **0.53** standard deviation.



	Level 0 Unawareness	Level 1 Awareness	Level 1.5 Awareness	Level 2 Supervised Practitioner	Level 2.5 Supervised Practitioner	Level 3 Practitioner	Level 4 Lead Practitioner	Level 5 Expert
INCOSE ASEPs				1				
INCOSE CSEPs		4	6	7	7	1		
INCOSE ESEPs		1	1	1	2	1		
INCOSE Non-SEPs		5	5	10	21			
Non-Members		1	3	9	3			

Figure 1: What is Engineering? A frequency distribution of the number of survey responses that scored at various SE technical core competency levels.

Findings – What is Engineering?

The distributions for all participant types – e.g., INCOSE ASEPs, CSEPs, ESEPs, and Non-SEPs, and as well as Non-Members - were relatively uniform across Levels 1 and 2 competencies. Interestingly, the INCOSE Non-SEPs exhibited higher levels of SE competence than other groups.

Question 2: What is Systems Engineering?

Question 2 investigates the survey participant's understanding of SE. Conceptually, every technically competent SE should understand the definition of SE and its attributes. Unfortunately, that is not the case. Professional organizations, academia, and others appear to be pre-occupied with SE's origin and context within the System Sciences, which is long over due. What is needed immediately is a *proven* definition of SE for engineers who actually develop systems, products, and services.

There are as many definitions of SE as personal opinions. So, what definition should be used to assess survey participant knowledge of what SE is? After reviewing several definitions, Wasson (2006, 2016) provides an *authoritative* definition of SE that expresses what SE is and accomplishes:

- **System Engineering (SE)** - The interdisciplinary (2018) application of analytical, mathematical, and scientific principles … for formulating, selecting, developing, and maturing an optimal solution from a set of viable candidates … that has acceptable risk, … satisfies User operational need(s), and … minimizes development and life cycle costs … while balancing Stakeholder interests (Wasson, 2016).

  Note: The "…" pauses above were inserted by the author to isolate key phrases of the definition to serve as criteria for assessing participant responses.

Recognize that this is more than a definition statement. It should serve as a *guiding mission statement* every work day and hung on their office wall.

Survey Results – What is System Engineering?

Table 4 provides participant responses to Question 2.

Table 4: Example Responses – What is Systems Engineering survey question.

INCOSE Competency Descriptor	**Competency Level**	**What is Systems Engineering** Assessment of Example Responses
Awareness	Level 1	Discipline to design, develop, or enhance a system or group of systems
	Level 1.5	SE is a discipline that studies the functionality of systems and inter-related systems
Supervised Practitioner	Level 2	SE is the art and science of using engineering to develop a system to meet user needs
	Level 2.5	Series of practices that holistically solves for an operational need by optimizing the entire solution, not a subset of it
Practitioner	Level 3	(No qualified responses)

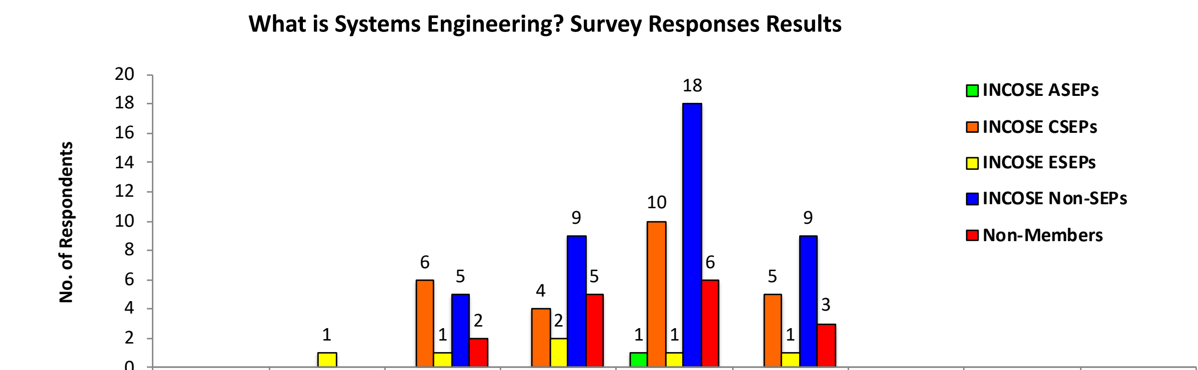
Figure 2 provides a frequency distribution of the Question 2 *What is System Engineering* assessment results. Survey participant responses ranged from a Level 0.5 Unaware to a Level 2.5 Supervised Practitioner. The Mean of the distribution was **1.96** on a 5.0 scale with a **0.51** standard deviation.

Survey Findings – What is SE? Referring to Figure 2, the distributions of ASEP, CSEP, ESEP, Non-SEP, and Non-Member groupings were generally interspersed within each other's distributions. Again, observe that the distribution for Non-SEPs reflected higher competency levels.

Question 3: What is a System?

Given an understanding of Engineering and SE, technically competent SEs need to understand *what* they are expected to "engineer" to accommodate a variety of user situations and operating environment conditions.

One of the cornerstones of the discipline of SE requires a fundamental understanding of *what a system is*. Numerous professional societies and standards organizations such as INCOSE, IEEE, ISO, et al have established definitions for defining a *system*. Within the context of their communities of practice, these definitions are fine; however, they are often high-level, abstract, philosophical expressions. SEs and engineers *who actually perform* SE require a frame of reference that relates to their everyday performance and drives their decision-making.



	Level 0 Unawareness	Level 0.5 Unawareness	Level 1 Awareness	Level 1.5 Awareness	Level 2 Supervised Practitioner	Level 2.5 Supervised Practitioner	Level 3 Practitioner	Level 4 Lead Practitioner	Level 5 Expert
INCOSE ASEPs					1				
INCOSE CSEPs			6	4	10	5			
INCOSE ESEPs		1	1	2	1	1			
INCOSE Non-SEPs			5	9	18	9			
Non-Members			2	5	6	3			

Figure 2: What is System Engineering? A frequency distribution of the number of survey responses that scored at various SE technical core competency levels.

After a review of various definitions of a system, Wasson (2016) provides an authoritative definition of a system that captures the key attributes of a system.

- **System** - An … integrated set of interoperable elements or entities, … each with specified and bounded capabilities, … configured in various combinations … that enable specific behaviors to emerge for Command and Control (C2) by Users … to achieve performance-based mission outcomes … in a prescribed operating environment …with a probability of success. (Wasson, 2016, p. 2)

  Note: The "…" pauses above were inserted by the author to isolate key phrases of the definition to serve as criteria for assessing participant responses.

If you challenge this definition, then apply a litmus test to your alternative definitions. The question is: *Would you allow yourself or a family member to board an aircraft, train, ship, or spaceship to Mars that was developed by SEs who viewed a system as a generic, abstract, "collection of things" or SEs who employed the definition above*?

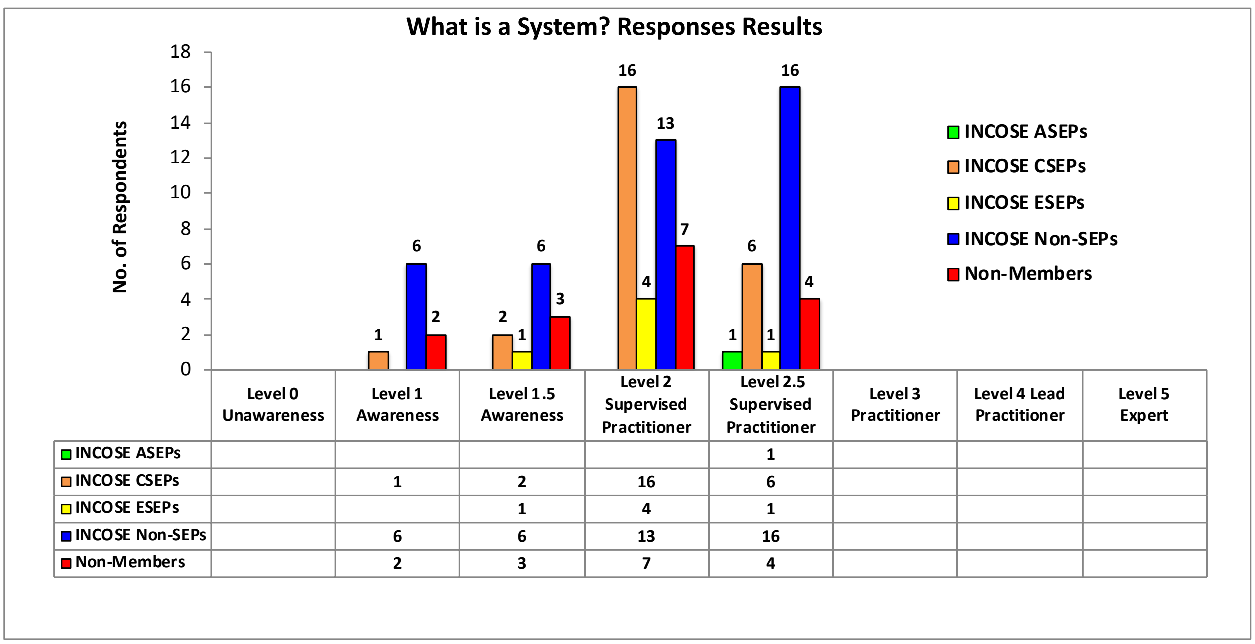
Survey Results – What is a System?

Table 5 provides illustrative examples of types of survey participant responses to Question 3.

Table 5: Example responses – What is a System survey question.

INCOSE Competency Descriptor	**Competency Level**	**What is a System?** Assessment of Example Survey Responses
Awareness	Level 1	A system is a human concept used to manage man-made problems.
	Level 1.5	A product that meets or satisfies a material need.
Supervised Practitioner	Level 2	Collection of entities integrated together to perform specified functions per its requirements.
	Level 2.5	An entity that can be decomposed into parts whereby the parts (alone) could not produce the functions or capabilities of the larger entity.
Practitioner	Level 3	(No Level 3 responses)

Figure 3 provides a frequency distribution of the survey participant responses to Question 3 What is a System? The assessment results ranged from a Level 1 Awareness to a Level 2.5 Supervised Practitioner. Observe that no survey participants qualified as a Level 3 Practitioner. The Mean of the distribution was **2.1** on a 5.0 (Highest) scale with a **0.50** standard deviation.



	Level 0 Unawareness	Level 1 Awareness	Level 1.5 Awareness	Level 2 Supervised Practitioner	Level 2.5 Supervised Practitioner	Level 3 Practitioner	Level 4 Lead Practitioner	Level 5 Expert
INCOSE ASEPs					1			
INCOSE CSEPs		1	2	16	6			
INCOSE ESEPs			1	4	1			
INCOSE Non-SEPs		6	6	13	16			
Non-Members		2	3	7	4			

Figure 3: What is a System? - Frequency distribution of the number of survey responses that scored at various SE technical core competency levels.

Question 4: What is a Capability?

System capabilities ultimately define the level of performance-based outcomes for a mission. For the past 60 years SE has been consumed with *functions* and *functional analysis*. Functions and functional analysis were a natural part of SE evolution and maturation. The reality is that functions and functional analysis are still relevant but have been *outdated* since that timeframe. Software engineering came to that conclusion in that timeframe. Yet, executives, functional managers, SEs, engineers, analysts, et al, continue to prod along with a *functional* mindset. Instead, the focus should be on Capability Analysis.

Capability Analysis investigates, analyzes and *derives* not only the functional action to be performed but also *quantifies* it with the performance value derived analytically, empirically via prototypes, or validated models and simulations. Unfortunately, executives, functional managers, project engineers, SEs, and engineers impress customers and refer to "capabilities" as if they were an abstract object with no lower level detail. Abstractness is fine in some contexts; however, their conversations seldom indicate a competent understanding of what a capability encompasses in terms of scope and technical depth. For example, the INCOSE SE Handbook (SEHv4, 2015), uses "capability" and "capabilities" numerous times. Yet, offers no definition.

So, *what is a capability*? Wasson (2016) defines the term as follows:

- **Capability** - An explicit, inherent feature… *initiated* or *activated* by an external stimulus, cue, or excitation… to perform an action (function)… at a specified level of performance… until terminated by external commands, timed completion, or resource depletion (Wasson, 2016, p. 2).

  Note: The "…" pauses above were inserted by the author to isolate key phrases of the definition to serve as criteria for assessing participant responses.

Implicit in this definition is the fact that each capability:

1. Has at least three phases of operation – i.e., Pre-Mission, Mission, and Post-Mission.
2. Is specified and bounded by a specification (functional) requirement statement.
3. Forms the basis for defining System Architecting and subsequently Command and Control (C2) either by the user/operator or the system's equipment.
4. Where appropriate, detects errors or hazardous conditions, attempts corrective actions, and if unsuccessful terminates to avoid safety risk to the system and its operators.

We will use this definition as the basis for assessing survey participant responses.

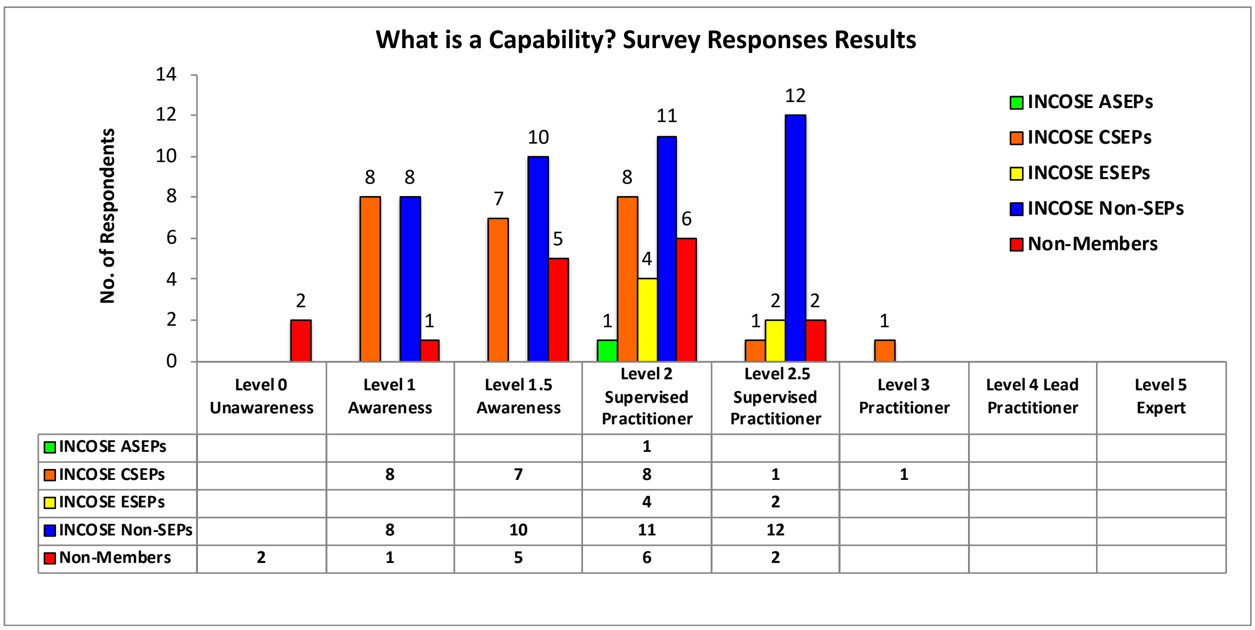
Survey Results – What is a Capability?

Table 6 provides illustrative examples of types of survey participant responses to Question 4 What is a Capability?.

Table 6: Example responses – What is a Capability survey question.

INCOSE Competency Descriptor	Competency Level	**What is a Capability?** Assessment of Example Survey Responses
Awareness	Level 1	Capacity / Ability to perform.
	Level 1.5	Ability of a system or team to accomplish a purpose.
Supervised Practitioner	Level 2	A feature, a function that performs a desired outcome.
	Level 2.5	A function of a system that can be defined, measured and exercised to meet the system's intended use
Practitioner	Level 3	The ability to produce a desired outcome under a predefined set of conditions based on a specified Measure of Effectiveness (MOE) & efficiency

Figure 4 provides a frequency distribution of the survey participant responses for Question 4 *What is a Capability*. Participant responses ranged from a Level 0 Unware to a Level 3 Practitioner. One INCOSE CSEP qualified as a Level 3 Practitioner. The mean of the distribution was **1.94** on a 5.0 (Highest) scale with a **0.58** standard distribution.



	Level 0 Unawareness	Level 1 Awareness	Level 1.5 Awareness	Level 2 Supervised Practitioner	Level 2.5 Supervised Practitioner	Level 3 Practitioner	Level 4 Lead Practitioner	Level 5 Expert
INCOSE ASEPs				1				
INCOSE CSEPs		8	7	8	1	1		
INCOSE ESEPs				4	2			
INCOSE Non-SEPs		8	10	11	12			
Non-Members	2	1	5	6	2			

Figure 4: What is a Capability? - Frequency distribution of the number of survey responses that scored at various SE technical core competency levels.

Findings – What is a capability?

As evidenced by the survey results in Figure 4, SEs and Engineers, in general, understand the context of a capability such as an abstract object; however, any lower level detail knowledge is suppressed. The reality is: a *capability* is a mini-system within it's own context and consists of attributes such as inputs, resources, constraints, phases of operation, architectural configurations, and performance-based outcomes.

Understanding the concept of system capabilities and their "cross-cutting" linkages flow across the system from stakeholders to the end deliverable system, product, or service is a critical SE core competency skill. Along that pathway, capabilities influence multi-level system architectures and designs.

The integrity of maintaining this process is best described by McCumber (2002, p. 4): The SE's job is to "… *maintain intellectual control over the problem-solution* …". When Level 1 or 2 SEs lack this requisite knowledge and experience, the Problem-Solution chain breaks, the SE loses *intellectual control*, and the project goes *high risk*. Figure 8 (Wasson, 2018) introduced later illustrates a key point by Kasser, et al (2009)– i.e., when a project requires Level 3-5 competency SEs but is staffed with with Level 1-2 competency SEs.

Question 5: What is the Underlying Concept of SE?

One of the hallmarks of any competent Engineering professional is understanding the core concept of their discipline. Question 5:

- Was purposely constrained to 6 words or less to get respondents to *think deeply* on their own and filter out all of the extraneous buzzwords and "talking points" that sometimes clutter everyone's minds.
- Seeks to understand *how well* survey participants understand the *essence* of what SE is intended to accomplish.

Question 5 delves deeply into the *inner core* of an SE requiring them to apply their Knowledge, Skills, and Attributes (KSAs) to answer the question. The phrase also captures the essence of Engineering. Engineers often spend four years in Engineering Programs as well a SEs in graduate programs and are never taught that basic concept.

From identification of stakeholders and their needs to deployment, operation, maintenance, sustainment, retirement, and disposal of the deliverable system, SE reduces down to one key phrase: *problem-solving and solution-development*. Those five words expressing two key concepts serve as the criteria for assessing survey participant responses.

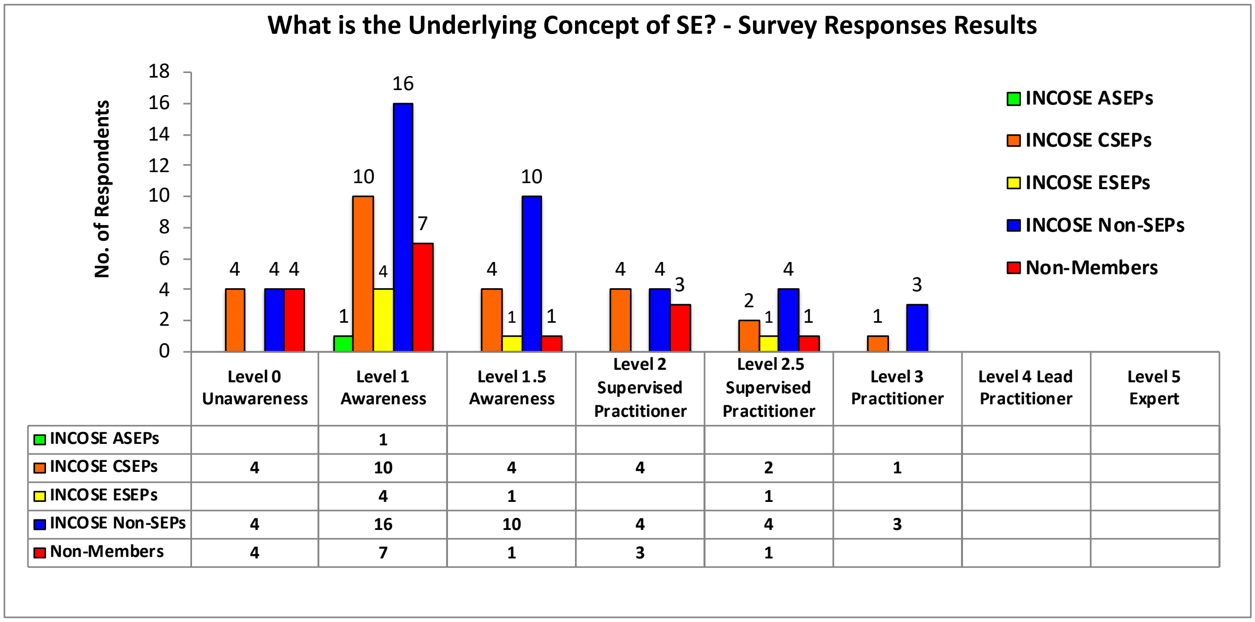
Survey Results – Underlying Concept of SE

Table 7 provides illustrative examples of types of survey participant responses to Question 5.

Table 7: Example Responses – What is the underlying concept of SE survey question.

INCOSE Competency Descriptor	Competency Level	**What is the Underlying Concept of SE?** Assessment of Example Survey Responses
Awareness	Level 1	Have a basic understanding of the system.
	Level 1.5	To develop the best solution.
Supervised Practitioner	Level 2	Looking at the problem holistically.
	Level 2.5	Understanding user needs and translating those needs into successful solutions meeting those needs.
Practitioner	Level 3	Holistic solutions to complex problems.

Figure 5 provides a frequency distribution of the survey participant responses for Question 5 *What is a Capability*. Participant responses ranged from a Level 0 Unawareness to a Level 3 Practitioner. Three (3) INCOSE Non-SEPs and one (1) INCOSE CSEP qualified as Level 3 Practitioner responses. The mean of the distribution was **1.76** on a 5.0 (Highest) scale with a **0.77** standard distribution.



	Level 0 Unawareness	Level 1 Awareness	Level 1.5 Awareness	Level 2 Supervised Practitioner	Level 2.5 Supervised Practitioner	Level 3 Practitioner	Level 4 Lead Practitioner	Level 5 Expert
INCOSE ASEPs		1						
INCOSE CSEPs	4	10	4	4	2	1		
INCOSE ESEPs		4	1		1			
INCOSE Non-SEPs	4	16	10	4	4	3		
Non-Members	4	7	1	3	1			

Figure 5: Underlying Concept of SE - Frequency distribution of the number of survey responses that scored at various SE technical core competency levels.

Findings – What is the Underlying Concept of SE?

1. Observe how the mean of the overall distribution is weighted to the left side of the figure.
2. Whereas the the quantity of INCOSE Non-SEPs is greater in the Level 2.5 range in previous survey question responses, observe its leftward shift toward Level 1 Awareness.

Question 6: Graphically Sketch and Annotate the SE Process.

One of the *least understood* SE concepts, yet gets the most publicity, is the SE Process. SEs and engineers are generally familiar with the Vee-Model of system development and its implementation. Some SEs are familiar with the original MIL-STD-499B (DRAFT) SE Process. However, there is a *general lack of understanding* of the relationship between these two concepts, which should be a hallmark of SE technical core competency.

Building on Question #5 “What is the Underlying Concept of SE”, Question 6 asks survey participants to graphically *sketch* and *annotate* the SE Process. The question was not intended to be a “trick” question. Instead, it was intended to assess *how well* survey participants understand a current or past SE problem-solving and solution development process such as Wasson, 2016; Mil-Std-499B-1994 (Draft), et al.

Survey Results – Graphically Sketch and Annotate the SE Process

Table 8 provides descriptive text of eample participant graphical responses to Question 6.

Table 8: Example Responses – Graphically depict and annotate the SE Process survey question.

INCOSE Competency Descriptor	Competency Level	Graphically Depict and Annotate the SE Process Example Responses (Author's text descriptors of graphic)
Awareness	Level 1	Plan => Implement => Evaluate => Improve ==> loopback to Plan
	Level 1.5	Develop Stakeholder Requirements => Synthesis => Define System Performance => Define Arch => Validate + Technical Oversight
Supervised Practitioner	Level 2	V-Model - Triangular graphic - Stakeholder Need => System functional Decomposition => Lowest Level => Verification => Realized System => Validation => Cycle back to Stakeholder Need (Note: The V-Model is not the SE Process)
	Level 2.5	V-Model annotated with System Levels (vertically - abstract) and Maturity (horizontal), swirls and arrows noting iterative and recursive development, System Levels of Abstraction (Vertical arrow) and System Maturity (Horizontally Left to Right) (Note: The V-Model is not the SE Process)
Practitioner	Level 3	No qualified responses

Note: Of the 89 responses to the survey, **No One** answered Question 6 correctly. As a result, a decision was made – rightly or wrongly - to assess and credit participant responses based on **what they know, have read, and have been taught**. Those results are shown in Figure 6 as an alternate frequency distribution.

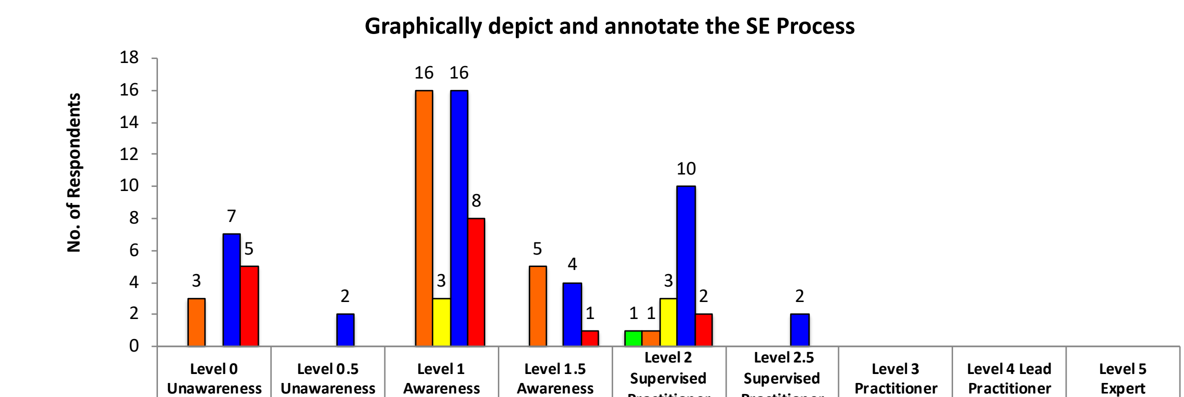
Findings – Graphically Sketch and Annotate the SE Process

Overall, the results for understanding the SE Process were *very poor* with few exceptions, especially since the SE Process is a key tool of SEs. To illustrate the dispersion of responses in what SEs think – i.e., perceive the SE Process to be, consider the following:

- 31 (34.8%) sketched a strategy-based workflow diagram; some with feedback loops.
- 22 (24.7 %) sketched the Vee-Model as their SE Process.
- 15 (16.9 %) sketched a System Development Life Cycle (SDLC) as their SE Process.
- 11 (12.4 %) sketched the Engineering Design Process (EDP) -e.g. specify, design, build, test, fix (SDBTF) - as their SE Process.
- 4 (4.5 %) provided no graphic but offered a general text description of an EDP process.
- 3 (3.4%) sketched an IDEF0 like chart – e.g. Box with inputs, resources, constraints, and outputs - as their SE Process.
- 2 (2.2 %) sketched the Spiral Development Process as their SE Process.

- 1 (1.1%) sketched box of processes similar to the ISO15288 framework.

Figure 6 provides a frequency distribution summarizing survey participant responses to Question 6. SE technical competency assessment scores ranged from Level 0 Unawareness to Level 2.5 Practitioner. There were no Level 3 Practitioner qualified responses. The Mean of the distribution was **1.49** on a 5.0 (highest) scale with a **0.66** standard distribution.



	Level 0 Unawareness	Level 0.5 Unawareness	Level 1 Awareness	Level 1.5 Awareness	Level 2 Supervised Practitioner	Level 2.5 Supervised Practitioner	Level 3 Practitioner	Level 4 Lead Practitioner	Level 5 Expert
INCOSE ASEPs					1				
INCOSE CSEPs	3		16	5	1				
INCOSE ESEPs			3		3				
INCOSE Non-SEPs	7	2	16	4	10	2			
Non-Members	5		8	1	2				

Figure 6: Graphically sketch and annotate the SE Process – No one answered Question 6 correctly. This is an alternate frequency distribution of the number of survey responses representing what SEs know, have read, and been taught.

Factors contributing to this condition include:

1. *Misinformation* on the Internet referring to the Vee-Model is the Systems Engineering Process. Forsberg and Mooz (1991 Exhibit 5, p. 60) clearly label and describe the Vee-Model concept as the "Project Cycle," not the SE Process.
2. Failure to replace former MIL-STD-499B (Draft) in commercial industry standards and promulgation of the process by some enterprises.
3. Absence of the SE Process in the INCOSE *SE Handbook* (2015).
4. Usage of ISO 15288 process framework in handbooks as the SE Process "Engine."
5. Lack of understanding of the SE Process by educational instructors and training vendors.

Figure 7 illustrates a current, correct SE Process and its application to the Vee-Model as one development model example (Wasson, 2006, 2018). This process: (1) corrects deficiencies in the Mil-Std-499B (Draft-1994) and (2) eliminates "quantum leaps" SDBTF Paradigm SEs and others take from specification requirements to a single-point, physical architecture solution.

As a conclusion to our survey data discussion, the average SE technical competency of Questions 1 – 6 was **1.90** on a 5.0 (highest) scale.

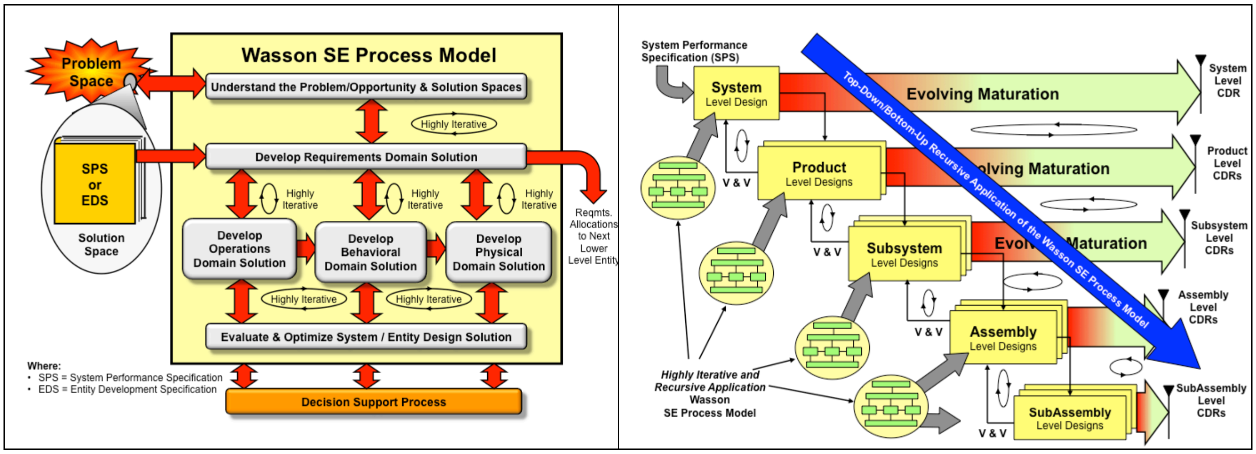


Figure 7: The Wasson SE Problem-Solving and Solution-Development Process Model (left) and its application (right) to the left side of the Vee-Model (Wasson, 2006, 2016).

Conclusions

Survey data from these six (6) questions clearly illustrate: (1) the impact of 60+ years of emphasis on SE Management and processes at the expense of SE technical core competency and (2) subsequent impact on project technical, cost, and schedule performance. Kasser, et al (2009, p. 7) observe that one of the reasons for poor project performance is the application of and dependence on Level 1 and Level 2 SEs on projects when, in fact, at a minimum, Level 3, Level 4, and Level 5 SEs may be required as illustrated in Figure 8 (Wasson, 2018).

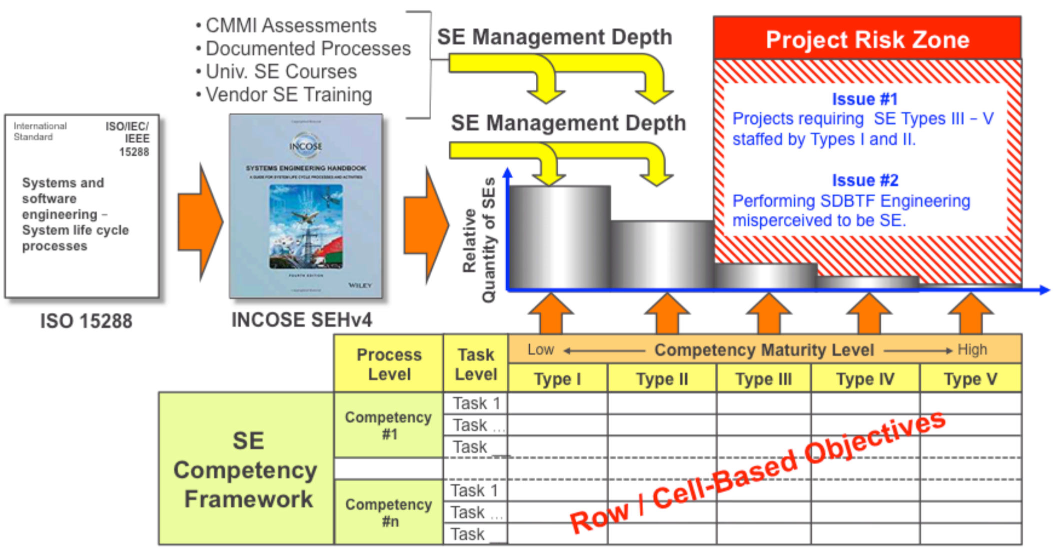


Figure 8: Relationships among SE Competency Frameworks, Kasser, et al (2009, p.6) five types of SEs, ISO 15288, the INCOSE SE Handbook, SE education, and performance issues. (Wasson, 2018)

One of the most significant findings that emerged from the survey data was the fact that INCOSE ASEP, CSEP, ESEP, Non-SEP member groups exhibited the same integrated dispersions in their assessment scoring levels. Whereas you might expect to see *higher levels* of clustering within certified SEP groups versus Non-SEPs or Non-Members, that did not occur; competency scores were all interspersed.

As the survey data in this project indicate, there are very few SEs who exhibit a Level 3 Practitioner or higher SE technical core competency. So, *how is SE accomplished*? Wasson (2018, p. 18) observes that most SEs are often level 3 or higher discipline engineers – e.g., EEs, MEs, et al – who are Systems Thinkers and very competent. Problems occur when an *unwitting* manager attempts to transfer a Level 4 EE, for example, into an SE organization and convert them into a Level 4 SE. Having a technical competency in one Engineering discipline does not automatically translate into a comparable level of competency in a different discipline like SE without requisite education and experience qualifications.

Additionally, based on the poor results of Question 6 Graphically Depict and Annotate the SE Process clearly indicate that SEs, in general, are **not well-grounded** in the SE Process. As the Question 6 survey data validate, enterprises and SEs often mistakenly employ a variety of *ad hoc, endless loop*, versions of the EDP or SDBTF Paradigm as their *defacto* SE Process, which is more applicable to research and investigative inquiry projects, not system development.

In summary, if you find the research survey results troubling, remember:

> *Every system (Figure 9) is perfectly designed to produce the results you are observing (Figure 10).*

SEs and engineers in the industry and government workplaces are product outcomes of the Engineering education system. Based on the author's industry experience, engineers are graduating without the requisite "systems" knowledge required for today's industrial and government environments. Every engineer should be required to complete an SE fundamentals course as a requirement for graduation. Wasson (2016, p. 40) observes that most engineers spend on average from 50% - 75% of their total career hours making systems decisions for which they have **no formal education**. As Wasson (2018) points out, the course textbook selection should be based on what the *engineer needs to perform in the workplace*, not the *instructor's comfort level with the subject matter*, namely SE management.

Recommendations for Advancing the State of SE Practice

System Engineering has been technically impacted over the past 60+ years due to the focus on SE management and processes. As a result, SE is often challenged by its interdisciplinary peers as to whether it is a vocational *profession* due to its focus on SE Management "soft skills" or an Engineering discipline. SE is neither; it is an interdisciplinary domain that encompasses more then Engineering. So, *how do we shift this outdated SE paradigm – e.g., "fix" the problem* as Griffin suggests (Warwick, 2010)?

First, industry, government, academia, textbook authors and publishers, professional societies, and standards organizations need to *recognize* the "gap" that exists between SE everyday practice versus the discipline of SE.

Secondly, the solution requires a *realignment* and directed *focus* to backfill SE technical core competency skills. As Wasson (2018) states, the SE Education and Standards Influence Chain leaders illustrated in Figure 9 need to:

1. Understand the Research Question – i.e., SE practice versus discipline of SE - stated earlier and the severity of its impact on project technical, cost, and schedule performance.
2. Commit to correct aspects of the paradigm within their areas of accountability.
3. Coordinate performance objectives and corrective actions with other organizational "actors" asshown in Figure 9 including a timetable.
4. Implement corrective actions.
5. Continuously monitor, assess, and correct SE technical competency to achieve performance objectives.

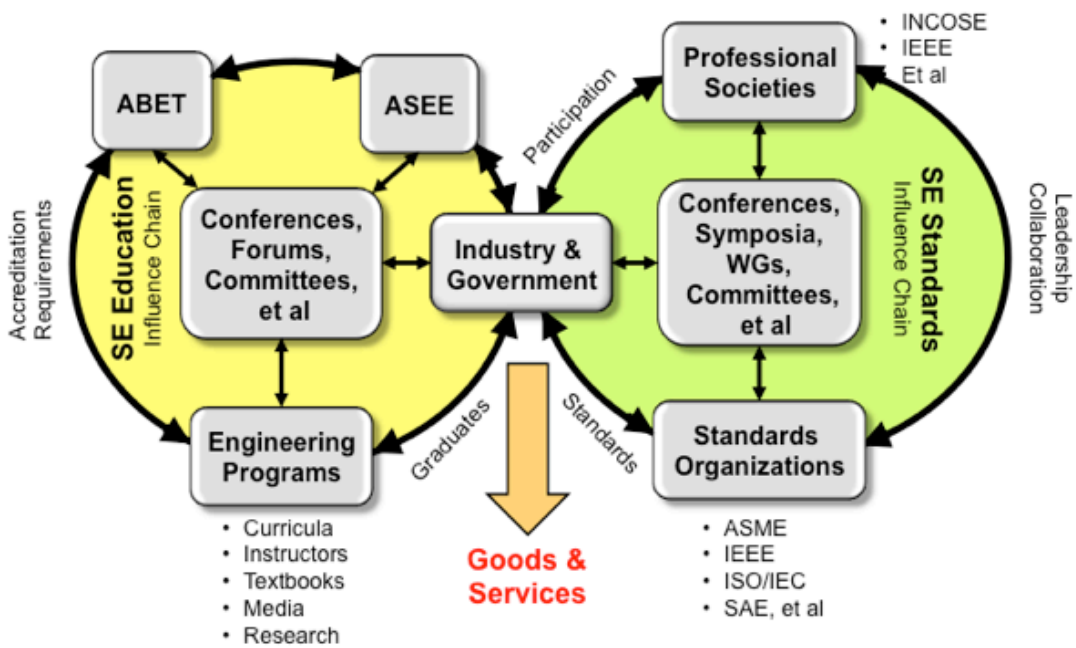


Figure 9: Industry and government are the "proving ground" for two influence chains: SE Education and SE Standards (Wasson, 2018).

Here's an additional challenge. Industry and government executives and managers need to:

1. Recognize the SDBTF Engineering paradigm lurking under the premise of SE within their Engineering organizations.
2. Understand *why* investments in SE Management processes; Capability Model Maturity Integration (CMMI) assessments; ISO 15288 compliance; INCOSE Handbook and SEP certification exams; et al over the years have had *limited success* by themselves in correcting project technical, cost, and schedule performance. These initiatives, while important, address *symptoms* of SE technical core competency neglect, not the source – *bonafide* SE education.
3. Recognize and accept accountability for solving your own enterprise SE capabilities and SE core competencies. Academic researchers, who typically lack in-depth, "hands on" industry

experience and do not understand the initial Problem Statement and its contributory causes, do not solve these SE and project performance issues. You have to "work in the trenches" of projects on a daily basis to understand challenges confronting SEs and engineers. Remember: Engineers and SEs perform the way they were educated, trained, and directed.

Given the SE Education and SE Standards Influence Chains in Figure 9, one of the organizations should to "step up" and lead the recalibration. INCOSE perceives itself as the standard bearer for SE; however, to fulfill this role INCOSE has to shift its focus on SE Management and processes and restore Engineering as the techncial cornerstone of the Systems Engineering discipline.

Finally, recognize that shifting the mindsets of the enterprises shown in Figure 9 requires shifting the SE Management "groupthink" paradigm that has persisted for over 60 years among those enterprises as illustrated in Figure 10 (Wasson, 2018, p. 18).

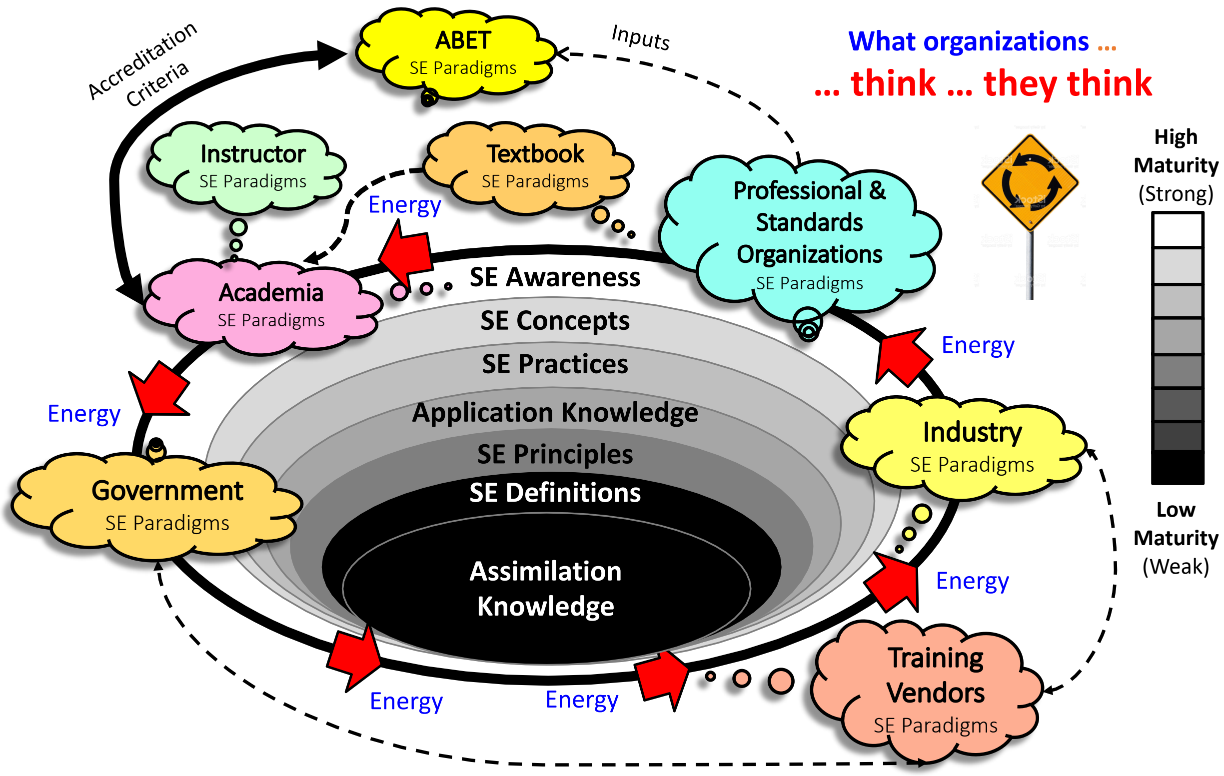


Figure 10: The "perfect storm" of SE Management "group think" and its impact on SE KSAs in a typical workplace based on SE core competency indicators. (Wasson, 2018, p. 15)

Summary

A very special thank you to our INCOSE ASEP, CSEP, ESEP, and Non-SEP colleagues in the five (5) INCOSE chapters in North America as well as non-members. These chapters and professionals gave freely of their meeting time and survey inputs in the interest of advancing the state of SE practice and the discipline of SE. The results of this survey are a reflection of the state of Engineering and Systems Engineering education or the lack thereof, professional and standards organizations, and others, not on these fine professionals who participated in the survey. The author expresses his sincere appreciation and respect.

This paper is intended serve as a "wakeup" and call to action to *motivate* industry and government executives and managers, professional societies and standards organizations, SEs, et al to take *corrective action*. Hopefully, the INCOSE FuSE Team will Read/reread Wasson's (2018) paper. Failure to shift this outdated paradigm only reinforces Engineering community perceptions as to whether SE is a *vocational profession* or a horizontal, interdisciplinary peer of the branches of Engineering governed by a rigorous set of concepts, principles, and practices and respected by its peers.

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Biography

Wasson, Charles, INCOSE Fellow and Certified ESEP, is the Founder and Principal Consultant for Wasson Strategics, LLC (WSL). His professional affiliations include the INCOSE, IEEE, ASEE, PMI, and Tau Beta Pi. His educational background includes BSEE and MBA degrees, a SE Certificate from Stevens Institute of Technology, and additional graduate studies.

Charles' professional experience includes over 38 years of leadership in project management; system, hardware, and software development; integration and test with Lockheed Martin Corporation; Teledyne Brown Engineering; U.S. Army Missile Research & Development, Command (MIRADCOM); Planning Research Corporation (PRC); Spacecraft, Inc. (SCI); and 12 years with Wasson Strategics, LLC as a professional SE training instructor and consultant.

Charles' first SE text *System Analysis, Design, and Development: Concepts, Principles, and Practices* won the International Academy of Astronautics' 2006 Engineering Sciences Book of the Year Award. In 2016, John Wiley published the 2nd Edition of his *System Engineering Analysis, Design and Development: Concepts, Principles, and Practices* text used world-wide by practitioners and universities.