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The Systems Engineering Conundrum:

Where is the ENGINEERING?

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Abstract. Systems Engineering, as an emerging discipline was transformed from the *Engineering of Systems* in the early 1950's to focus on *Managing the Development of Systems* with a new Systems Management approach. The transformation was initiated to resolve conflicts between Engineering and Management paradigms that contributed to failures in post-WWII complex system development and integration of new technologies. By today's standards, the transformation was a *partial solution* with *unintended consequences*, namely Systems Engineering's qualifications as an Engineering Discipline. … *Where is the Engineering?*

To answer the question, we explore the SE Technical Competency Gap, *what it is* and *how it evolved*, explore its impact on the *Engineering of Systems* that contributes to project technical, cost, and schedule performance issues SE is intended to minimize, and illustrate how the lack of a core technical framework that defines its concepts, principles, and practices leads to the proliferation of *misinformation* by the *uninformed*. Ultimately, the SE global community has a *conundrum* – continue its unwitting Systems Management approach under the premise of SE … or … to institute corrective actions to … *restore* … SE technical core competency qualifications as a bonafide, maturing Engineering Discipline to where it should be today postures for the future.

Executive Overview

Individuals, enterprises, professions, societies, et al sometimes become consumed with a blissful, complacent condition of "groupthink" or paradigm. For example, humans believed the "Earth was flat" … until approximately 300 B.C. when Eratosthenes disproved the paradigm. For context, let's define a paradigm:

- **Paradigm** – A mental model, mindset, or set of norms of an individual, team, community, or society – e.g., "groupthink" – that becomes mesmerized by its own beliefs and value system and rejects external beliefs or suggestions until an internal revelation motivates or external event intervention causes a shift to a new way of thinking.

Corporate enterprise survival requires having a *sustainable* vision supported by strategic and tactical plans for *affordable* systems, products, or services that the marketplace needs. Adizes (1988) and Barker (1992) describe how enterprises as well as individuals, professions, and societies, fail or succeed and must continually evolve as new technologies and methods become available.

The *lesson learned* is that individuals, enterprises, professions, societies, and others must be in a continual state of assessing the state of its paradigms. Systems Engineering and the International Council on Systems Engineering (INCOSE) are no exceptions.

Systems Engineering (SE), as an Engineering Discipline, exists along a *continuum of realism and depth of competency* between two extremes. At one extreme are SEs accountable for leading interdisciplinary teams developing systems, products, and services for the benefit of society. At the other extreme are *theorists* who study *systems* and *holism* relative to the Systems of Systems (SoS) within the universe.

This paper addresses real-world Engineering … where system, product, or services success is subject to the hard realities of enterprise, individual, and societal marketplace paradigms interacting with user operational needs, fickleness, acceptance, and satisfaction; physics and the environment, and the realities of "do no harm" as well as business profitability and survival must coexist in balance.

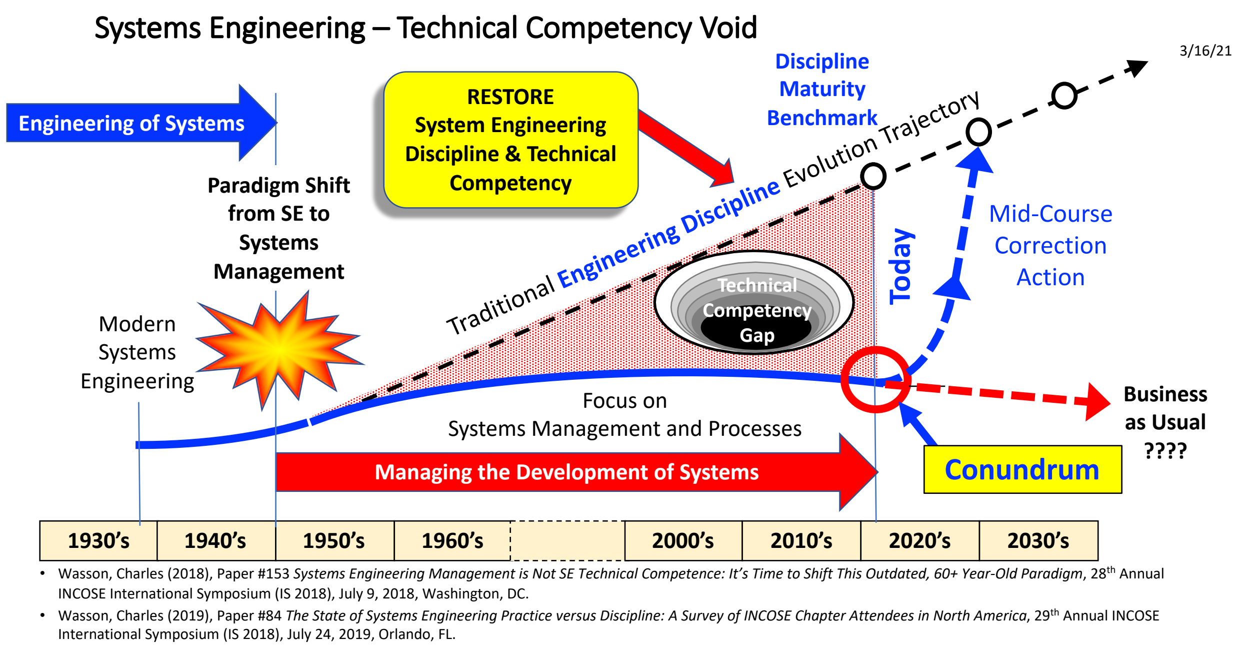


Figure 1: The Systems Engineering Technical Competency Gap and Conundrum

In the early 1950's, SE was transformed from an emerging Engineering Discipline focused on the *Engineering of Systems* (paradigm) to *Managing the Development of Systems* (paradigm) as shown in Figure 1. The transformation was motivated by a significant number of system development and technology integration failures occurring on complex military projects integrating new technologies. Contributory root causes were traceable to deeply-rooted and conflicting Management-Engineering paradigms.

1. Johnson (2013, p. 677) notes that "Project managers were frustrated by scientists and engineers, who had *such a radically different way of thinking*."

2. Drucker (1974, pp. 176-177) referred to the engineers and scientists of that timeframe as "knowledge workers." Johnson (2002b, p. 228) adds "… In earlier times, managers could directly understand and control the workers (Engineers). With knowledge workers, this was no longer possible …"

As a result:

1. Systems Management, namely Project Management (PM) and Configuration Management (CM), processes were instituted to enable managers to gain *authoritative control* over Engineers"(Johnson, 2002, 2013).

2. (Johnson, 2002b, p.2) notes "These *systems engineers* created and maintained documents that reflected the current design and they coordinated design changes with all those involved in the program. Perceptive managers and military officers realized that *central design coordination* allowed them to gain control of both the creative process and its *lively if unruly knowledge workers*."

Summarizing, Discipline Engineers who were Systems Thinkers and understood *systems* were designated as SEs and relegated to *communication and coordination* roles on projects.

Over the past 60+ years, Systems Management processes and practices have flourished at the expense of SE technical competency, which has essentially been ignored as an Engineering Discipline (Wasson, 2018, p. 1). Over the past 30 years, the author has collected quotes from meetings and other sources that characterize SE and SEs as follows:

1. SE is "a mile-wide and an inch deep technically" (McCumber, 1998).

2. Systems Engineering is one of the most abused job labor categories in Industry … everyone is an SE whether qualified or not. (Wasson, 2018, p. 6)

3. Other Engineering disciplines question "is SE is an Engineering Discipline or just a profession?" (Dixit and Valerdi, 2007)

4. "Perhaps SE would enjoy greater success if it, too, were taught in business schools as a management skill rather than in engineering departments?" (Emes, et al, 2005, , p. 178).

5. PMs observe: "Engineers can never finish a design on time or within budget! They are always 'tinkering' with the design! (Wasson, 2018, p. 8)

6. SE practiced in many enterprises is typically just a traditional, *ad hoc, circular, endless loop* process derivative of the Scientific Method intended for scientific inquiries and investigations, not SE and development. Wasson (2016, p. 17, 19).

7. Most SEs are typically highly competent, Discipline Engineers who are Systems Thinkers, may have had a high-level, SE education course(s) or vendor training; and a Level 1 or 2 out of 5 understanding of generalized SE concepts and practices. (Wasson, 2018, p. 6)

Whereas these quotes may seem counter to the long-standing SE "talking points," after 38 years in various SE leadership roles for major corporations recognized for their SE and 14 years as an SE Organizational Development consultant in eight business sectors, the quotes have validity.

The subtitle of this paper - *Where is the Engineering?* - forms the technical basis of this paper. The Systems Management paradigm over the past 60+ years has become so in-grained as evidenced by SE command media – e.g., policies, standards, handbooks, processes, such as certifications, and textbooks on the topic *unwittingly mislabeled* as "Systems Engineering" are presumed to define the scope of SE. As a point of reference, let's define the contexts of Systems Management and SE used as a frame of reference in this paper.

- **Systems Management** - "A set of organizational structures and processes to rapidly produce a novel but dependable technological artifact within a predictable budget Johnson (2002b, p. 17).
- **Systems Engineering** - The multi(inter)-disciplinary application of analytical, mathematical, and scientific principles to formulating, selecting, developing, and maturing a solution that has acceptable risk, satisfies User operational need(s), and minimizes development and life cycle costs while balancing Stakeholder interests. Wasson (2016, p. 2)

SE in some enterprises has evolved or devolved into perceptions of SEs being technical managers who "communicate and coordinate" what everyone else should be doing. In contrast, genuine SEs do perform technical management roles as well as "leading" and being fully accountable for the integrity of the interdisciplinary Engineering technical effort. Depending on the *size* and *complexity* of the Engineering project, there may be SEs at different levels of responsibility required to perform varying combinations of those roles.

SE, as a genuine Engineering Discipline, is about *accountability* and "*maintaining intellectual control of the problem-solution space*" (McCumber 2002, p. 4) via *application* of SE KSAs; leadership; and interdisciplinary Engineering integration to deliver the end product, not vice versa. *It's not a hobby*! If you fail to perform your job, … everything from customer satisfaction, marketplace acceptance … to … user injury or death, depending on the system, are potential consequences.

What is important is *educating* SEs and Discipline Engineers with the requisite Knowledge, Skills, and Abilities (KSAs) in SE concepts, principles, and practices for productive employment in industry and government beginning on Day #1. They understand *systems* and their assigned System of Interest (SOI) tasks within the project's System of Systems (SoS). However, here's the irony. All Engineers typically are required to complete General Engineering courses such as Engineering Statics and Dynamics, Thermodynamics, Engineering Materials, Engineering economy, an others.

Anecdotally, Wasson (2016, p. 40) estimates that most Engineers graduate and spend, on average, from 50% to 70% of their total career hours making "systems" related decisions for which they have … *no formal SE education*.

Based on the preceding discussion, the *conundrum* to be resolved as illustrated in Figure 1 is:

> *Should the global SE community continue its "business as usual" approach of "Managing the Development of Systems" while ignoring the SE Technical Competency Gap … or … institute strategic and tactical corrective actions to restore SE Discipline and technical competency as a qualifications Engineering Discipline?*

Literature Search

The publications by the authors listed below address the need for organizations to recognize paradigms that limit the effectiveness of the organization, highlight perceptions of SE and SEs, trace the historical background of SE, its implementation, and provide solutions.

- Cowper and Smith, 2003
- Dixit and Valerdi, 2007
- Emes, Smith, and Cowper, 2005
- Griffin, 2010
- Johnson, 2002a, 202b, and , 2013
- Ring, 2017
- Slegers, Kadish, Payton, Thomas, Griffin, and Dumbacher, 2012
- Wasson , 2010, 2012, 2018, and 2019

Problem Statement

Despite "Engineering" being a key part of its name, "Systems Engineering" command media, in general, exhibit a plethora of objective evidence on Systems Management and Processes and only inferences of a complete set of science and math-based concepts, principles, and practices unique to SE that guide its application.

Need for a Standard SE Frame of Reference

In 1969, former NASA Administrator Frosch (1969, p. 5) observed:

> "From time to time I am briefed on the results of a systems analysis or systems engineering job in a way that prompts me to ask the questions: "That's fine, but is it a good system? Do you like it? Is it harmonious? Is it an *elegant solution* to a real problem?" For an answer I usually get a blank stare and a facial expression that suggests I have just said something really obscene."

Years later in 2010, former NASA administrator Dr. Michael Griffin authored a paper titled "How Do We Fix Systems Engineering" (2010, pp. 3 - 5), which expanded on Frosch's observation and proposed four criteria for defining an elegant system (author additions below).

1. How do you know the design will actually work (in its prescribed operating environment and produce the performance-based outcomes the user expects)?
2. Will the design be robust (to accommodate internal or externally-induced failures and complete its mission)?
3. Will the design be efficient (in its usage and resources to complete its mission)?

4. How do we ensure that the design will not have design flaws, errors, and deficiencies that result in unintended consequences?

Author's Note: Usage of the term, *elegant system*, may seem unusual due to in-grained connotations from the fashion industry. For this paper's context, we will use *elegant system*.

Watson, Mesmer, and Farrington (2020, further elaborate *elegant systems* criteria in Section *1.3 Characteristics of an Elegant System* (pp. 7 – 9) and Section 4.4 System Design and Integration (pp. 42 - 174). In addition to Griffin's (2010) criteria, they add "*Efficacy*: How well does the system achieve the intended outcomes? (p. 8) " One critical consideration in system development, *system integrating physics* (p. 44 - 95), is seldom addressed in SE command media including SE competency indicators.

The importance of these criteria is paramount as a context for any type of system. In the case of Engineered Systems, the elegant system criteria apply to the deliverable SOI as well as a project's *organizational* SOI developing the … *deliverable* SOI. These criteria apply to SE research systems and as well as SE educational systems – e.g., Accreditation Board of Engineering and Technology (ABET) accredited Engineering Programs that "produce" work products" – e.g., graduates, that must be capable of performing, not only as individuals, but as contributing members to project interdisciplinary Engineering teams.

After 60+ years of in-grained *Managing the Development of Systems*, *Is SE's glass half empty or half filled*? Psychologist, Gestalt, created a series of optical illusion artworks that ask the viewer "what do you see?" Some see SE as *Systems Engineering* based on what they may have read, told, or taught, a paradigm. They *perceive/misperceive* themselves as *living the dream* – e.g., Systems Management paradigm - and "fully qualified as competent in SE," especially when *certified* by INCOSE. Others question SE as an Engineering Discipline and see SE as a *glass … half filled*.

To illustrate the point, when factual SE information reveals deficiencies in SE as an Engineering Discipline, those realities are characterized as "whining and pejorative." Emes et al. (2005, p. 178) reinforce this point and cite Cowper and Smith (2003) who "identify the key barriers to promoting and 'selling' systems engineering as: the lack of SE awareness and understanding, the lack of a clear message about what SE is or is not, the confusion over the Systems Engineer's skill set, the need for a business case for SE, and the management of implementation risks."

SE Semantics. To further illustrate how the *lack of consistency* in SE standards across business domains, industry, government, and academia are left to their own contextual definitions. Which definition should you subscribe? Typically, you will hear … "I *kinda* like this definition." To illustrate the point, consider the following example.

The US DoD standardized terms, definitions, and usage across services and agencies for many decades. Later as commercial industry embraced SE concepts, principles, and practices, the DoD Acquisition Reform in 1994 transitioned standards accountability, in general, to industry. DoD SE terms, which in some cases were unique to military organizations, were *stigmatized* by commercial industry as unique to Aerospace & Defense (A&D). They *unwittingly rejected* the terms and definitions as *unrelated* to their business domain systems, products, or services. Examples include terms such as *mission; mission objectives; operational needs, Concept of Operations (Con-Ops); phases modes, and states; command and control (C2), situational awareness, and many others*.

The reality is these terms: (1) are not *unique* to A&D other than a longer history of usage, (2) are common to other Engineering disciplines such as EE, and (3) apply to any type of Engineered System such automobiles, medical devices, computers, educational systems, businesses, and others. Learn to recognize *how* and *when* SE concepts *universally apply* to any system, product, or service regardless of business domain!

Summarizing, SE needs an *authoritative source* for SE standardization such as IEEE for EE.

Understanding the Impact of the Systems Management Approach

The Systems Management approach consisting of Project Management (PM) and Configuration Management brought a level of managerial and technical discipline convergence to system development in the early 1950's.

In the years following the Systems Management decision, the USAF introduced a series of Systems Management standards from 1966 through 1994 to ensure requirements for system acquisition were established to preserve the integrity of their projects for avoiding technical, cost, and schedule performance issues. Examples were:

- USAF AFSC 375-5 (1966) *Systems Management*
- Mil-Std-499 (1969) *Systems Engineering Management*
- Mil-Std-499A (1974) *Engineering Management*
- Mil-Std-499B (Draft - 1994) *Systems Engineering*

Observe the operative term, "Management," in each of the titles until it was changed to "Systems Engineering" in Mil-Std-499B (Draft - 1994), which was not approved in lieu of transitioning to commercial standards. Unfortunately, the standards listed above became the focal points for system development as well as education for Engineers unfamiliar with SE. As an unintended consequence, the scope of the standards became *implicitly imprinted* in the minds of Engineers as representing the *scope* and *depth* of SE as an Engineering Discipline.

To better understand the impact of the Systems Management approach on SE Technical Competency, let's explore the topic from an Engineering perspective using Figure 2.

Starting with the left side of Figure 2, traditional Engineering Disciplines are based on a set of science and math-based concepts; laws. theorems, and principles; and practices. In contrast, SE is defined by Systems Management command media consisting of standards, handbooks, processes, certifications, and others. SE Technical Competency represented by the virtual cloud formation, which should define the "Engineering of Systems," consists of a few high-level, abstract concepts, principles, and practices as represented by the diminishing lower portion of the framework.

Woolfolk (1998, pp. 244-283) identifies three types of knowledge:

1. Declarative Knowledge –*What Tos*

2. Procedural Knowledge – *How Tos* and *Why Tos* (Wasson, 2020)

3. Conditional Knowledge – *When Tos* and *Where Tos*

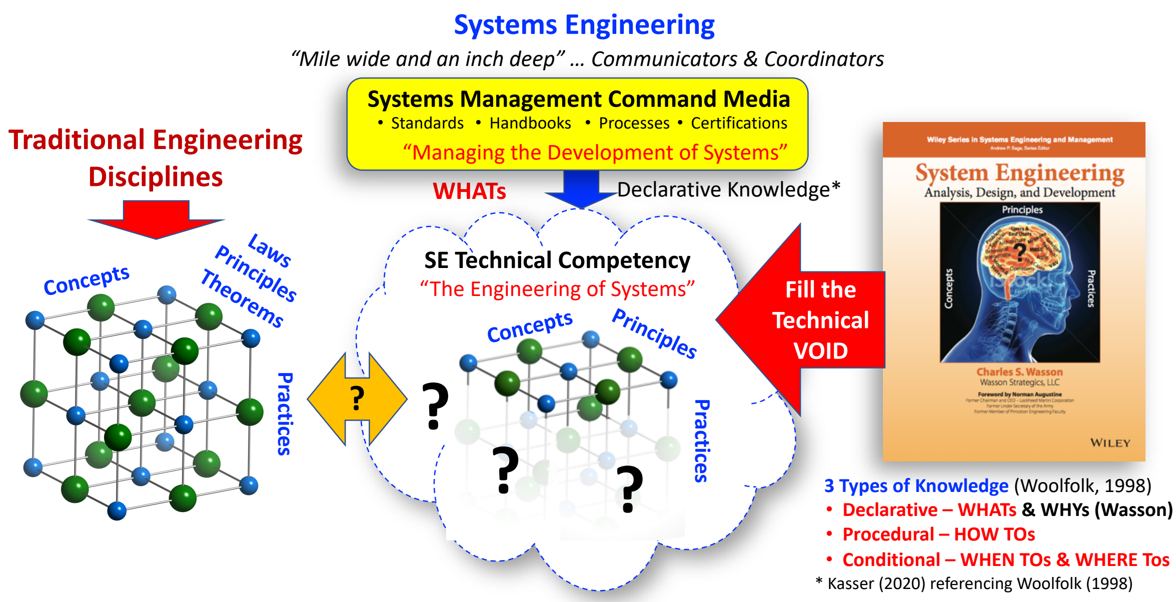


Figure 2: Solving the Systems Engineering Technical Competency Gap

The Systems Management portion of SE, which prescribes *What* must be accomplished, clearly aligns with Woolfolk's Declarative Knowledge. Such is the case for ISO/IEC 15288:2015 and the INCOSE SE Handbook (2015) traceable to ISO 15288. The level of detail in ISO 15288 is certainly appropriate as a standard; however, it purposely *does not* prescribe… *How To* perform SE.

Central to this discussion is the delineation of *What* versus *How*. A key principle of SE is specifications that expresses *what* is to be accomplished, not *how*. Command media prescribe *what* is to be accomplished, not *how*. Therefore, requirements such as identify stakeholders and needs, develop use cases, write specification requirements, develop a system architecture, and others … are appropriate for the *scope* and *depth* for the document type.

What is missing from this level of command media? Namely, Woolfolk's Procedural and Conditional Knowledge. There are pockets of Procedural and Conditional Knowledge within INCOSE's command media. However, the question is: *How and where do SEs* turn to learn the *How To's, Why To's, When To's, and Where To's of SE as addressed by Wasson (2016, Figure 2.12, p.39) and McCumber and Sloan (2002, p. 3)*

In today's world, system development, is highly dependent on interdisciplinary SE that includes SEs and Discipline Engineers. What is needed is a genuine SE course that fills the Technical Competency Gap in Figure 2. As foundational course for undergraduate or graduate level SE curricula, this course is not some "homegrown" course by an educator with little or no industry experience and a set of generic slides or Systems Management course and textbook each *unwittingly* mislabeled as *Systems Engineering*. As a frame of reference, refer to Wasson (2016).

What really happens in the lower levels of the SE technical competency framework in Figure 2?

Using an Earth cutaway analogy, SE command media comprise the outer crust and mantle layers of SE. Below these levels is the inner core representing the *inferno* where the interdisciplinary Engineering of Systems is performed and … *magic happens*. To illustrate how *magic happens*, let's review the historical evolution of a few SE practices, Figure 3 uses the Earth's crust and mantle as an illustration.

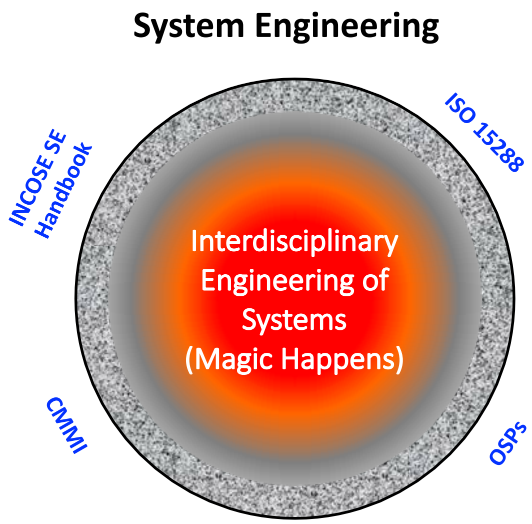


Figure 3: SE Earth Crust and Mantle Analogy

In the 1980's documenting processes were all the rage as a means for correcting project technical, cost, and schedule performance. Everyone *documented their OSPs* … irrespective of whether the processes were *effective* or *efficient* from an SE perspective. SEs and Discipline Engineers were "bubble-wrapped" in processes with the expectation of improving project performance, which it did ... to diminishing level.

Processes are very important for planning and synchronizing Engineering performance. Wasson (2016, p. 24) refers to Engineers applying processes without requisite SE education as *Paint-By-Number Engineering*. Processes by themselves *do not* achieve project success. Competent SEs and Discipline Engineers properly educated in SE concepts, principles, and practices using the OSPs in combination with innovation and creativity postures projects for success.

In the late 1980's and early 1990's concepts such as Concurrent Engineering and Integrated Product and Process Development (IPPD) were introduced to ensure the right disciplines were introduced to ensure timely integration of the right Engineering disciplines "Just in Time" during system development to improve decision-making. (Interdisciplinary) Integrated Product Teams (IPTs) were formed to focus on specific system/product development efforts and … *follow their tailored OSPs*. IPTs were trained in *how to* conduct meetings, make decisions, deal with conflicts, etc. Project performance improved to a degree.

Although these initiatives were *necessary*, they were *insufficient* and had one critical issue in common. They failed to establish and teach interdisciplinary SE as an Engineering Discipline required to develop systems, products, and services. As a result, Discipline Engineers – e.g., EEs, MEs, SwEs, et al - joined teams and brought different: sets of: semantics, mental frames of reference, problem-solving methodologies, processes, and tools. *Is there any wonder why after 30+ years of OSPs, JIT IPTs, SE command media, et al that ... magic happens in system development*?

As objective evidence of how the "magic happens" in Figure 2, consider the following examples:

Example 1 Enterprise Brands of SE. Wasson (2016, pp. 36 - 37) observes if you ask enterprise managers and executives to describe their SE process and performance results, they lament that "it could be better and it isn't perfect … but neither is Engineering!" If you suggest consideration of a better, improved SE process, they immediately shift into a defensive posture and say "that is a 'different 'brand' of SE than we (have)."

Generally speaking, there is only one "*brand"* or *standard* of SE as currently defined in ISO/IEC 15288:2015. Effectively, what many of these executives and managers are saying is … they have their own "home-grown" Engineering *problem-solving and solution-development* approach such as the Engineering Development Process (EDP) or Specify-Design-Build-Test-Fix (SDBTF) Wasson, 2016, Figure 2.8, p. 33) paradigm. They acknowledge their SE Process is *inefficient* and *ineffective*. Interestingly, they have heard that a genuine, methodology-based SE Process such as Figure 7 is *iterative and recursive*. Since their (EDP or SDBTF) SE Process is … *iterative and recursive*, it is valid. That is debatable … in terms of what it is intended to accomplish and poor habits to correct as well as its *efficiency* and *effectiveness*!

Example 2 US GAO Reports. Wasson (2018, p. 18), observes "…GAO 17-77 (2016) highlights the correlation between project technical, cost, and schedule performance and the introduction of SE early into the acquisition process. For example, their findings note that the lack of SE or late involvement by SE *correlates* with low project performance in the form of technical risks, cost and schedule overruns, and so forth." GAO reports only provide a general reference to SE without regard to a reference standard or the *brand* of SE that is their frame of reference, which seems odd for auditing purposes, especially when a key purpose is corrective action and improvement.

Standard SE Competency Frame of Reference

What SE needs is a "standard" frame of reference for educating, training, and evaluating SE technical performance. SE has a technical competency frame of reference via the INCOSE Competency Framework (INCOSE, 2018). The challenge is the framework is dependent on a decision authority to interpret the criteria for assessing SE technical competency of an individual. Again, we're back to *ambiguities* and *inconsistencies* in SE competency. Realistically, one enterprise may assess an individual to be at Level X; another enterprise may assess that same individual as a Level X +/-, which may be critical for hiring decisions if used as a qualification.

When left to the *whims, strengths, and weaknesses* of a manager with varying levels of SE competency, the integrity of the process comes into question. While the INCOSE SE Competency Framework (INCOSE, 2018) is certainly a step in the right direction, SE competency ultimately comes down to … *can an SE actually demonstrate and develop systems, products, or services that meet well-defined criteria*, not interpret, frame, and "spin" SE semantics to a set of competency criteria. Let's explore this point further.

To alleviate this ambiguity and risk, a recognized authoritative certification source such as a professional organization or university course should require: (1) completion of a course with a comprehensive examination using Wasson (2016) as a frame of reference, (2) an application documenting SE accomplishments, and (3) a comprehensive interview based on objective evidence in the application. Example Systems Thinking examination and interview questions are:

1. Sketch and describe in detail the end-to-end thread from Stakeholder identification to specification requirements, explain each of the steps including *why* and *sequencing*, *how to* assess completeness, verification, and validation (V&V).

2. Sketch and describe in detail the architecture of the SE Process shown in Figure 7, its sequential steps and what the sequencing is intended to accomplish and avoid, and its iterative and recursive application to the System Architecture.

Again, the INCOSE Competency Framework (INCOSE, 2018) is fine; however, the question is … *can the SE candidate actually demonstrate their capability to perform and apply SE to their business domain systems, products, and services*?

How Do Most SEs Learn the Discipline

Engineers learn SE initially and collectively two ways: (1) *formally* via university courses or (2) *informally* supplemented by experiential learning over many end-to-end lifecycle projects in different roles over 20 years or so. Observe the phrase "end-to-end lifecycle projects in different roles," not incomplete fragments of projects. Additionally, McCumber and Sloan (2002, p. 3) share insights concerning the SE education and types of thinking including the "Why, What, How, and How Well of a problem solution.

- **Formal Knowledge** – Conceptually, formal Engineering and SE Education provides proper taxonomical *coverage* and *completeness* of an Engineering Discipline's topics that include its concepts, principles, and practices. The challenge is (1) the educator's qualifications, namely teaching and in-depth industry experience in SE over many end-to-end projects over 20 years or more.

- **Experiential Knowledge** - In general, most SEs learn SE *informally* and *experientially* over many years. Typically, most SEs acquire SE knowledge *experientially* by *osmosis* in the workplace– i.e., such as listening, learning the semantics lingo from meetings and watercooler conversations; reading *unvetted* publications on-line; participating in "in-house" SE training vendor presentations titled "Systems Engineering (i.e., Systems Management).

Wasson (2016, Figure 2.12, p. 39) illustrates comparisons of these two types of SE Learning.

A word about SE handbooks and textbooks.

- **SE Handbooks.** Over the past 60-+ years, governmental and professional organizations have produced SE handbooks that express how the enterprises expect SE to be performed based on best practices and lessons learned. Prior to the Internet, government and corporate SE handbooks for many decades served as "textbooks" for Discipline and System Engineers who had limited access to university SE courses, libraries, and bookstores.

  Government handbooks, for example, filled an SE *educational void* but had unintended consequences. Since handbooks are often labeled *(Organization) Systems Engineering Handbook*, it may implicitly misrepresent the scope of their contents in two ways:

  - **Context** - Many of these handbooks are intended as system *acquisition and development* guides for the organization's personnel *performing oversight and implementation of system development contracts*, not the Engineering of Systems.

  - **Scope** – *System acquisition and development oversight* involves Managing the Development of Systems.

  The *context* and *scope* of any textbook should match its title and vice versa. For example, The INCOSE *SE Handbook* (2015) is appropriately subtitled *A Guide for System Lifecycle Processes and Activities*.

- **SE Textbooks.** Textbooks are often written by researchers, educators, or practitioners, who may or may not have in-depth industry experience or misperceive Systems Management to be the scope of SE (Wasson, 2018, p. 10).

  These texts often have "Systems Engineering" titles. Yet, the scope of their contents may be limited to high-level abstract SE discussions such as Systems Management or simply "about SE." Exacerbating the problem are subtitle claims of "principles" and overblown marketing claims of being the best-selling guides for developing complex systems when the text is only introductory. *Textbook titles should match the contents and vice versa*.

  When SEs and Discipline Engineers say they have had an SE course, the next question concerns course *scope* and *depth*. Textbooks are sometimes selected by edict, the instructor's "comfort zone" - e.g., knowledge and experience, or preferably the needs of students to complement the understanding of their discipline in industry and government.

ABET Contributions. The US Accreditation Board of Engineering and Technology (ABET) Engineering Accreditation Commission (EAC) establishes Criterion 3 Student Outcomes for Engineering Programs including Systems Engineering. Despite an ABET (2020 – 2021) SE Program Criteria banner and all the formal introductory words of professional organizations including the INCOSE participating in defining the requirements, the section simply states … "There are no program-specific criteria beyond the General Criteria" (ABET, 2020-2021, p. 38). Unfortunately, this statement has been in the SE Program Criteria section since at least the 2012 – 2013 edition of the document – 8 years!

Rhetorically speaking based on the ABET EAC General Criteria, - Criteria 3 Student Outcomes (ABET, 2020-2021, pp. 5 - 6) , an Engineering Program can hypothetically create an SE course taught by a novice instructor with no in-depth industry experience and "check the box" of satisfying all seven of the criteria. I'm sure that is not the case but it does raise the question … .*Where is the System Engineering?*

Given this background, let's investigate how the: (1) Technical Competency Gap identified in Figure 1 and (2) lack of a core framework of SE concepts, principles, and practices scoped in Figure 2 lead to misinformation, which proliferates around the internet and other sources.

Learning to Recognize Systems Engineering Misinformation

As a result of the 1950's Systems Management decision, individuals and enterprises sometimes create their own *interpretations* of what SE is and *unwittingly proliferate* information via Internet websites, conference papers, and so forth … based on their own competency level. You need to be vigilant of how SE information gets distorted and validate information from reputable sources.

Let's explore a few classic examples and instances.

System Development Process. SEs, Engineers, and others often confuse the V-Model of System Development, a projects system Development Process, and the Systems Engineering Process. When you lack a genuine SE course based on Wasson's (2016) textbook and/or have an instructor who does not fully understand the differences between the V-Model and a generic System Development Process placeholder to accommodate any one of several Development Models such as the V-Model, Spiral, Iterative and Incremental, Agile, and others, confusion occurs.

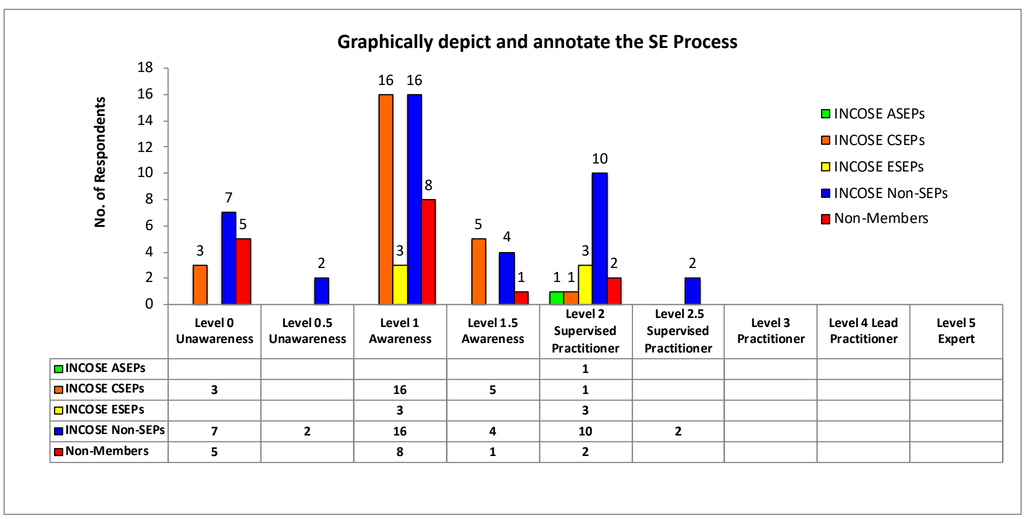
Wasson (2019) presents results from a 2017 – 2018 SE competency survey of INCOSE member and non-INCOSE member attendees at chapter meetings in North America. The survey, which had a time-constraint of 20 minutes, asked six questions representing foundational knowledge indicative of SE technical competency. Survey questions were:

1. What is Engineering?
2. What is SE?
3. What is a System?
4. What is a Capability?
5. In 6 words or less, what is the essence of SE?
6. Graphically sketch and annotate the SE Process

Overall, the average technical competency was only 1.8 on a 5.0 scale. Of the 89 responses to the survey, **no one answered Question 6 correctly**. Answers ranged from the V-Model to the (1) EDP or SDBTF Engineering Paradigms or (2) Scientific method. As a result, a decision was made to assess and credit participant responses based on what they know, have read, have been told, and / or have been taught.

Survey Question 6 results are summarized graphically in Figure 4. Reviewing the results, it is interesting that:

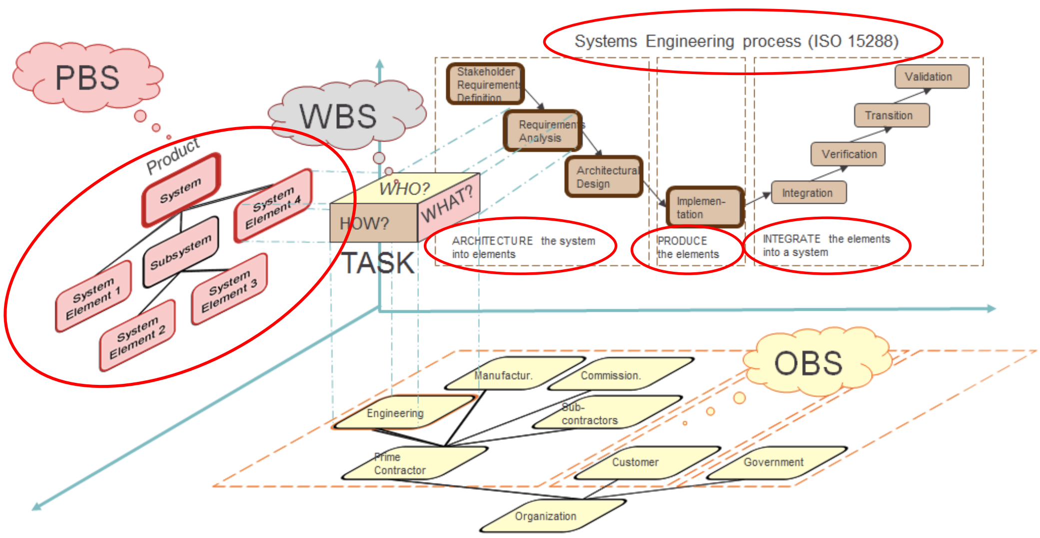
1. Non-Members and INCOSE Non-SEPs, one ASEP, and ESPs scored the highest.
2. Most of INCOSE CSEPs scored at Levels 0 to 1.5, which seems to correlate with the INCOSE *SE Handbook* (2015) as a Level 2 SE technical competency document.



	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 4: Wasson (2019) SE Competency Survey – Question 6: Graphically Depict and Annotate the Systems Engineering Process

To further illustrate and validate these results consider the INCOSE PM-SE Integration Team graphic shown in Figure 5. The author understands this graphic was derived from “other sources.” The intent of the diagram is to illustrate in 3-D the linking relationships between a project’s Work Breakdown Structure (WBS), Product Breakdown Structure (PBS), and the Organizational Breakdown Structure (OBS) map to cost account tasks. There are several flaws in the graphic as noted by the red ovals.



Source: INCOSE PM-SE Integration Working Group, Oct. 14, 2020, Slide 19/54.

Figure 5: INCOSE PM-SE Integration Team – Strategic Technical Planning Initiative Chart

- **WBS (Work Breakdown Structure)** – The WBS *plane* consists of a classical V-Model illustration and is titled “Systems Engineering Process.” Several flaws: (1) The V-Model *is not* the SE Process discussed later, (2) ISO/IEC 15288:201588 purposely *does not* specify Development Models, and (3) System Acquirers such as the DoD specify their own standard WBS structures for compliance. The author learned that the context of the ISO 15288 reference as actually an annotation indicating traceability to ISO/IEC 15288:2015. Unfortunately, it was positioned in the wrong location on the page.

- **PBS (Product Breakdown Structure)** – A PBS is intended to represent the physical hierarchical composition of a system. The PBS shown in Figure 5 is a case of intermixing SE semantics – i.e., System Elements, Subsystem, et al, *inappropriately* and *unnecessarily*. These semantics have unique *contexts*, *applications*, and *meanings*. Another reason for having an SE technical standard.

    - **System, subsystems, assemblies,** et al are *entity* or *item* designations assigned to various system architecture levels of abstraction containing two or more entities or components – e.g., Subsystem 1, Subsystem 2, and so forth.

    - **System Elements** are: (1) **general classifications** of types of *items* that comprise an entity or item within any level of abstraction and (2) consist of: Personnel, Equipment, Mission Resources, Procedurals Data, Outcomes, and Facilities (where applicable). They do have **relevance to** a PBS, but **NOT ON this diagram**, which overly complicates the chart’s message.

> The INCOSE SE Handbook (2015) is filled with references to the System Elements but never defines what they are, their relationship to a System Architecture, application and context of usage. Refer to Wasson (2016, pp. 174 - 196) to learn more about these semantics and their application.

Fortunately, the flaws were identified and corrective actions recommended.

System Engineering Process. Based our discussion above concerning a Project Cycle or generic System Development Process placeholder , let's address the SE Process and how the SE Process is *misapplied*. If you search the Internet for Systems Engineering Process, the results reveal a plethora of diagrams (Figure 6) by organizations that are unaware of the difference between a Systems Development Process such as the V-Model and a bonafide SE Process. This is an example of Enterprise Brands of SE discussed earlier.

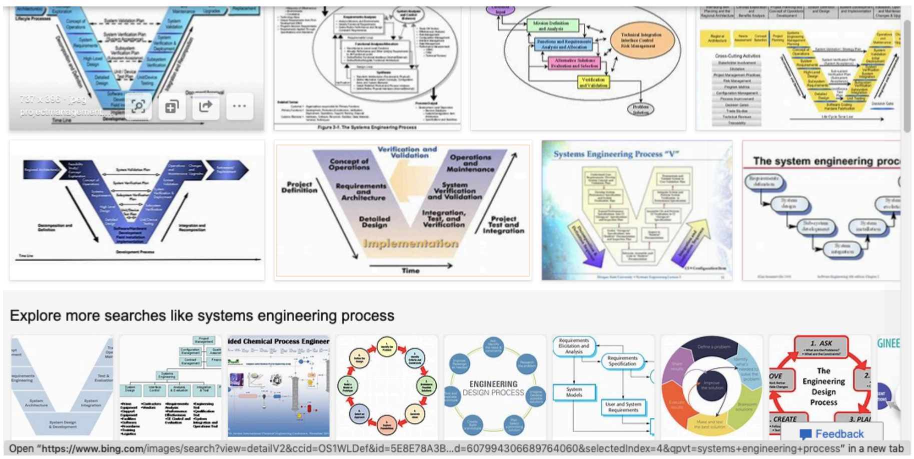


Figure 6: Internet search results for SE Process reveals misinformation in understanding the difference between Systems Development Process models versus the actual SE Process.

The Systems Engineering Process is a *problem solving and solution-development* process that applies to any *entity* or *item* within any System Architecture level of abstraction. As such the SE Process is analogous to the Scientific Method for conducting *scientific research, inquiries*, and *investigations*. The SE Process shown in Figure 7 and Scientific Method serve different purposes and applications. As a result, each is based on a different methodology.

If you conduct an Internet search for SE Process, you will find numerous examples as shown in Figure 6. In general, these examples are of three types: V-Model discussed above, former MIL-STD-499B (Draft), and circular. Many of the circular models are derivatives of the Scientific Method. Since we have already discussed the V-Model above, we will address only the circular and 499B (Draft) processes.

- **MIL-STD-499B (Draft) SE Process** – The 499B standard, as noted earlier was never approved in lieu of DoD Acquisition Reform, which transitioned development and maintenance of standards to industry. Although its SE Process was state of the practice in 1994, based SE practice-based knowledge today, it has been *outdated for decades*.

- **Circular SE Process**es – Most iterative, circular-shaped, endless loop, activity-based, processes are derivatives of the Scientific Method, which is *applicable to scientific inquiries and investigations, not SE and development.* One of the example is traditional the Engineering Design Process (EDP) commonly found on the Internet.

  Wasson (2016, Figure 2.8, p. 33) identifies a similar process based on Specify-Design-Build-Test-Fix (SDBTF) Engineering paradigm commonly in industry. The SDBTF Process, which is also a derivative of the Scientific Method, originates in K-12, migrates through higher-education Engineering Programs *unchecked* and *unmitigated* as a "problem solving method" by educators. Engineering students implicitly learn and validate the process experientially in the lab when problems occur. Labs are often time-constrained "get it finished" exercises rather than … understanding a design flaw, set-up configuration, or process and mentally storing it for future occurrence. The SDBTF migrates into industry where the paradigm has been *thriving* and *growing* by under the *unwitting* scrutiny of enterprise SE, managers, and executives for decades.

  Where is the System Engineering?

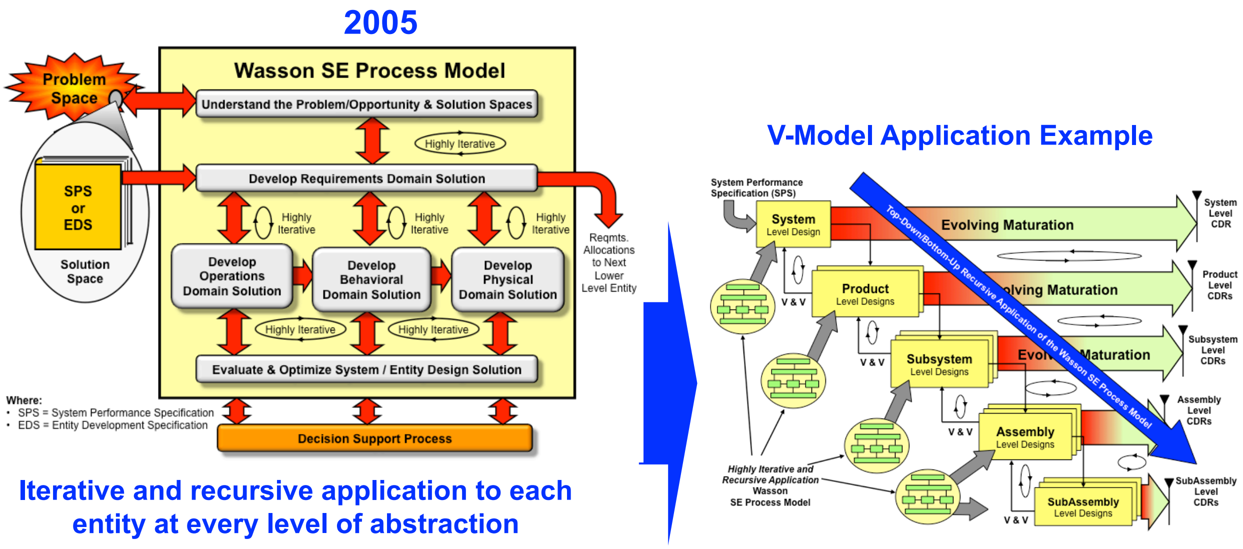
Both the EDP and SDBTF paradigms are traditional, *ad hoc, endless loop* processes that are *inefficient* and *ineffective*. As SE *activity-based* processes, PMs lament that Engineers can never seem to finish tasks or projects. For example, "Perform XXXX Test" is an activity versus "XXXX Testing Completed," a performance-based outcome. This example exemplifies *how* technical competency issues resulting in rework contribute to project cost overruns and late schedule delivery performance issues (Wasson, 2018, Figure 4, p. 7).

> If the process and team's focus is performing SE *activities*, you get activities. If the process focuses on *performance-based outcomes*, you get performance based "outcomes." *Is there any question why system development projects have a reputation for being delivered late?*

What SE Process should SEs and enterprises use?

Wasson (2016, Figure 14.1, p. 298) provides the solution. The SE Process, shown on the left side of Figure 7 is a true SE Process that is performance-based. Whereas many SE Processes as based on … academic research opinions, the structural framework for this process is a science-based methodology developed to overcome a major Engineering problem. Engineers, due to a lack of proper Engineering Education, have a reputation for taking a *quantum leap* from requirements to a physical solution (Wasson, 2016, Figure 2.3, p. 22) before they understand a user's operational needs, how they intend to employ the system, what behavioral capabilities and performance it must provide, and how they plan to deploy, operate, maintain, and sustain it when delivered.

The Wasson SE Process framework shown in Figure 7 consists of sequential steps that enable SEs to *incrementally* and *iteratively* evolve translate the problem-space for an entity or item e.g., system, subsystems, assembly, etc. - at any level of abstraction into a solution that is *traceable vertically and horizontally* to the system's *originating requirements*. Each entity solution is developed and evolved *iteratively* through its Four Domain Solutions – i.e., Requirements ➔ Operations ➔ Behavioral ➔ Physical - to maturity. Concurrently, requirements traceability is maintained to each Four Domain Solutions in combination with evaluating and optimizing the overall performance of the entity's Four Domain Solutions. Wasson (2016, pp. 294 – 312) elaborates and describes the SE Process Model and elaborates the Engineering of these steps in detail.



Source: Wasson, *The State of Systems Engineering Technical versus Discipline: A Survey of INCOSE Chapters Across North America*, Figure 7, p. 22, INCOSE IS2019, Orlando, FL, July 24, 2019.

Figure 7: Example illustrating Wasson's Systems Engineering Process applied to levels of abstraction and entities within each level of the V-Model.

As a *problem-solving and solution-development* methodology, the SE Process is applied from the System Level downward to each level of abstraction and entity within each level as shown on the right side of Figure 7 Wasson, 2016, Figure 14.9, p. 306) in combination with the development of the System Architecture candidates. Compared to previously noted SE Processes, the Wasson SE Process is *performance outcome-based, efficient, and effective*. It provides a common, reliable, easy to understand method for interdisciplinary SE teams to employ and overcome the *magic happens* illustrated earlier in Figure 3.

System Phases, Modes, and States of Operation. This topic is one of the least understood concepts in SE, *topically* and *contextually* within the realms of requirements analysis, system architecture development, and system design. For example, everything is a States, no Modes; some say States and Modes or vice versa, and other confusing points. Wasson (2016, Chapter 7, pp. 147 – 172) provides a very comprehensive and complete end-to-end discussion on this topic and its relationship to requirements analysis, system architecture development, and system design.

Where is the Engineering … of a system's phases, modes, and states of operation?

SE Professionals (SEPs) Certifications. – Individuals and enterprises have spent significant resources certifying personnel as SE Professionals (SEPs) based on the INCOSE *SE Handbook: A Guide for System Life Cycle Processes and Activities*, not SE technical competency. Although certification, in general, is a step in the right direction, some enterprises perceive SEPs to be SE *technically competent* as well, which is not the case.

Where is the Engineering … technical core competency certification?

ISO/IEC 15288:2015. SEs often believe ISO 15288 flowed down to the INCOSE Handbook as filling the Technical Competency Gap. Specifically, ISO/IEC 15288:2015 Section 6.3, which addresses *Technical Management Processes*, not *HOW TO Perform* …System Engineering. As discussed earlier, ISO 15288 exemplifies Woolfolk's Declarative Knowledge – *Whats*, which is appropriate for the standard. It *does not prescribe* SE Procedural Knowledge –*How Tos*, or Conditional Knowledge – *When To's* and *Where To's* that comprise SE Technical Competency.

Model-Based Systems Engineering (MBSE). MBSE provides a powerful work environment for the *Engineering of Systems* as a Digital Engineering environment. Although many people erroneously perceive MBSE to be a modern day phenomenon, its roots trace back to at least the 1950's. Since then, computers have become more powerful and their modeling language software applications have become more specific to SE applications.

Technology advances must be met with equivalent KSAs to properly apply and use them. Engineers have long-standing reputations for being able to learn a tool "out of the box" by "hacking" through drop down menus and basic instincts from using other tools without effectively learning a tool's capabilities. MBSE is a classic example. MBSE platforms are based on relational databases and modeling applications that enable populating data structures based on an Entity Relationships Diagram (ERD) schema and *linking* the data to enable searching, tracing, evaluating completeness, and so forth.

In an MBSE presentation (Anonymous, 2020), a project made a decision to employ an MBSE tool to model a large, legacy system. The project lead noted that Engineers could manipulate the tool; however, they didn't understand SE or how to apply it to a system. In that context, the power of an MBSE tool is diminished to little more than a relational database for linking data structures to one another to facilitate traceability, searches, and printouts – e.g., Digital Engineering.

Wasson (2016, pp. 226 – 242, 505) provides Engineering constructs for technical decision-making that drive many MBSE decisions concerning human-system interactions such as situational assessment, Command and Control, and others.

Where is the Engineering ... in MBSE?

- Griffin (2010, p.2) observes "While at its core systems engineering is concerned with interfaces between separable system elements, it should be realized that the more important concerns the dynamic behavior between the elements, not the numbers in the Interface Control Document (ICD)."

- Griffin (Warwick and Norris, 2010) also notes that "What is needed is a new view that the core SE function is not primarily concerned with characterizing the interactions between elements and verifying that they are as intended. What's more important, he says, is *understanding the dynamic behavior of those interactions*."

Being competent in SE, understanding the physics of a design solution (Watson, Mesmer, and Farrington, 2020, pp 44 – 95) and its interactions modeled with an MBSE tool and modeling language enables the full capability and power of MBSE to emerge and be exploited. Noguchi (2016) also provides additional MBSE insights and lessons learned.

Monolithic Enterprise Definitions. INCOSE, like most professional organizations, has evolved into a monolithic enterprise for *establishing* and *flowing down* definitions. In recent years, INCOSE has adopted a new vision "A better world through a systems approach" and interests that extend far beyond Systems Engineering. As INCOSE expands its interests to encompass related but non-SE and Engineering disciplines is a key heuristic based on the author's experience:

> *The utility of definitions to accommodate a widely diverse audience ... is inversely proportional ... to the breadth of users' interests*.

When there is a need to develop or update definitions, a high-level team of Fellows and other volunteers is formed to establish definitions that will pass academic scrutiny for subsequent dissemination to the membership.

The reality is SEs who develop systems, products, or services often work on projects that are typically *understaffed* … with highly *aggressive* schedules and *limited* budgets … and do not have the time to unravel the abstractness of each term within a definition. They need definitions that are *clearly* and *succinctly* stated with *substantive* meanings they can relate to their work.

Dixit and Valerdi (2007, p. 3) observe that "Each of these (Table 1 – Ramo, Friedman, Sage, Blanchard, and Fabrycky) definitions are appropriate for different situations. Each of them contains a different perspective representative of the application of the principles of systems engineering. Instead of INCOSE's monolithic enterprise ""one size fits all" definitions that exemplify Wasson's heuristic above, author proposes a concept of *contextual definitions* to accommodate member contexts such as business sectors or system applications. Here are a couple of illustrative examples.

Example 3. In 2018, INCOSE updated its definitions of "System" and "Systems Engineering." Here are example definitions of an *Engineered System* as viewed from a Systems (high-level) and an SE (working level) perspectives.

Table 1: Comparisons of *Engineered System* definitions from Systems and SE perspectives.

Systems Perspective	Systems Engineering Perspective
Engineered system – "a system designed or adapted to interact with an anticipated operational environment to achieve one or more intended purposes while complying with applicable constraints" (INCOSE, 2019, p. 3).	**Engineered System Definition** — "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 & Control (C2) by Users to achieve performance-based mission outcomes in a prescribed operating environment with a probability of success." (Wasson, 2016, p. 2).

Compare and contrast the two perspectives.

- The Systems perspective is a high-level *all things to all people* definition.
- The SE perspective intended for "hands-on" system development *addresses* a systems composition, *why* it exists, *what* it is intended to accomplish, *where* it operates, *how* it is

controlled, and *what* level of results are expected. Use the one that best applies to your work or enterprise projects.

If uncertain about a definition relevant to your situation, "test" the definition …by asking yourself a simple question. If you develop aircraft or an automobile, for example, *would you allow yourself or a family member to board the aircraft or drive/ride in an automobile in which the System Developer and their engineers built the system using the Systems Perspective or the SE Perspective*? Contextual *relevance* and *specificity* make a difference!

For SEs who work in corporate environments that audit projects for contractual and technical compliance, every engineer should understand how their tasking *fits within and relates to* the system being developed. The SE Perspective definitions provides such a framework.

Example 4. Systems Engineering Definition

In this example, we illustrate differences in perspectives in defining Systems Engineering as shown in Table 2.

Table 2: Comparisons of *System Engineering* definitions based on Systems and SE perspectives.

Systems Perspective	SE Perspective
Systems Engineering Definition – "is a transdisciplinary and integrative approach to enable the successful realization, use, and retirement of engineered systems, using systems principles and concepts, and scientific, technological, and management methods." (INCOSE, 2019, p. 3)	**Systems Engineering Definition** – "The multi(inter)-disciplinary application of analytical, mathematical, and scientific principles to formulating, selecting, developing, and maturing a solution that has acceptable risk, satisfies User operational need(s), and minimizes development and life cycle costs while balancing Stakeholder interests." Wasson, 2016, p. XX)

Summary

The global SE Community and INCOSE have a *conundrum*: *Where are the SE standards that define SE best practices as an Engineering Discipline and an SE's KSAs that will restore SE Discipline and Technical Competency and fill the SE Technical Competency Gap in SE command media and Engineering Education*? Referring to Figure 1, does SE and the INCOSE:

- Continue its *business as usual, appro*ach that ignores the Technical Competency Gap and contributes to project technical, cost, and schedule performance issues and *continue to move away from Systems Engineering* into related disciplines – e.g., General Systems Theory that includes Systems Philosophy, Systems Sciences, and Systems Technology (Bertalanffy, 1972, p. 414 – 424) each with their own respective professional societies - in its "A better world through a systems approach" (INCOSE, 2021)?
- Or … institute a mid-course correction via a series of incremental strategic and tactical steps that Restore System Engineering Discipline and Technical Competency to reestablish SE's credibility and integrity as an Engineering discipline among its peers?

INCOSE 2014-2015 President David Long in a presentation titled *Building for Tomorrow: 21st Century Systems Engineering* (Long, 2014, Slide 5) talked about "systems thinking, systems science, systems dynamics, the systems perspective, and absolutely systems engineering. He:

- "… noted that all brought value with systems engineering as the interventional piece.
- … and noted more than once that if INCOSE were named today (in 2014/2015), I believe the organizational title would have been broader than SE." (Long, 2021)

Given INCOSE broadening its interests in SE applications to "systems," in general, how will INCOSE resolve its SE conundrum – e.g., Where is the Engineering? and organizationally restore SE discipline and technical competency as an Engineering Discipline?

One potential solution to the conundrum may not be an "A versus B" decision but rather a combination of the two options. In the Winter 2020/2021 issue of the American Society of Engineering Education (ASEE) *Prism Magazine*, Petroski (2021, p. 19) addresses a similar situation concerning the American Society of Civil Engineers (ASCE).

> "A society of engineers by its very name implies a condition for membership. ASCE (American Society of Civil engineers) got around this by establishing sub-societies called *institutes*, which non-engineers can join. Thus, geologists and other scientists working in areas related to building design and construction are welcome to join ASCE's Structures Institute. Ironically, ICE (Institute of Civil Engineering) calls its *sub-institutes societies*!"

From the author's perspective, Systems Engineering is the key focal point in INCOSE's legal name. As Petroski noted above concerning how ASCE handled a similar situation, perhaps INCOSE can continue to evolve well into the future as the INCOSE and create an organizational structure within for Systems Philosophy, Systems Sciences, and Systems Technology as special interest groups or similar designation that strengthen the SE discipline integration and serve as liaisons with their respective organizations without infringing on their charters and disciplines.

In recent years, INCOSE leadership has expressed concerns about new members joining and allowing their memberships to expire after a couple of years. INCOSE conducts annual surveys of new members, especially interests and reasons for joining but apparently does not follow-up as to the reasons… *why* … memberships were not renewed. There could be a variety of reasons, one of which is addressed in this paper.

> *Rhetorically, …based on survey data collected by INCOSE (Boyer and Picard). do new members join to learn more about … Systems Engineering … and discover mostly something different, namely systems and Systems Management?*

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Biography

Wasson, Charles, INCOSE Fellow and Certified ESEP, is the Founder, Thought Leader, and Principal Consultant for Wasson Strategics, LLC (WSL) Professional affiliations include the INCOSE, IEEE, ASEE, PMI, and Tau Beta Pi. His core competencies include: Interdisciplinary Systems Engineering, Technical Project Management, Organizational Development (OD), and Team Development.

Charles' professional experience includes:

- Over 38 years of leadership in technical project management leadership; technical planning, stakeholder/user requirements development; system, hardware, and software development; integration and test, and verification & Validation (V&V).
- 14 years with Wasson Strategics, LLC as SE Organizational Development (OD) consultant and training instructor advancing the state of Systems Engineering,

As an internationally recognized author and consultant, his accomplishments include: commencement presentations and professional speaking engagements, numerous conference papers and presentations, and two textbooks published by John Wiley & Sons, Inc. (New York) in world-wide use by educators, researchers, and practitioners.

- 2006 - *System Analysis, Design, and Development: Concepts, Principles, and Practices, 1st Edition,* selected for by the IAA for its 2006 Engineering Sciences Book of the Year Award.
- 2016 - *System Engineering Analysis, Design and Development: Concepts, Principles, and Practices,* 2nd Edition.