Guide to the Systems Engineering Body of Knowledge (SEBoK)

v. 1.4

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Contents

Articles

References

Part 1: SEBoK Introduction

SEBoK Introduction

Systems engineering (SE) is essential to the success of many human endeavors. As systems increase in scale and complexity, SE is increasingly recognized worldwide for its importance in their development, deployment, operation, and evolution.

The purpose of the *Guide to the Systems Engineering Body of Knowledge (SEBoK)* is to provide a widely accepted, community-based, and regularly updated baseline of SE knowledge. This baseline will strengthen the mutual understanding across the many disciplines involved in developing and operating systems. Shortfalls in such mutual understanding are a major source of system failures, which have increasingly severe impacts as systems become more global, interactive, and critical.

Key Terms

A good first step towards understanding is to define key terms. Four terms will suffice for this introduction: system, engineered system, systems engineering, and systems engineer.

Here are baseline definitions of what these terms mean for the purposes of the SEBoK:

- A system is "a collection of elements and a collection of inter-relationships amongst the elements such that they can be viewed as a bounded whole relative to the elements around them". Open systems exist in an environment described by related systems with which they may interact and conditions to which they may respond. *Element* is used in its very broadest sense to include anything from simple physical things to complex organisms (including people), environments and technologies, to organizations of people, information or ideas.
- An engineered system is an open system of technical or sociotechnical elements that exhibits emergent properties not exhibited by its individual elements. It is created by and for people; has a purpose, with multiple views; satisfies key stakeholders' value propositions; has a life cycle and evolution dynamics; has a boundary and an external environment; and is part of a system-of-interest hierarchy.

Note: while there are many definitions of the word "system," the SEBoK authors believe that this definition encompasses most of those which are relevant to SE. Engineered system is a specialization of system which fulfills the basic properties of all systems but which is explicitly man-made, contains technology, exists for a purpose and is engineered through a series of managed life cycle activities to make it better able to achieve that purpose. This definition was developed for the SEBoK in an attempt to position SE as part of the wider world of systems research and practice without in any way detracting from other more abstract or philosophical uses of systems ideas.

- Systems engineering is "an interdisciplinary approach and means to enable the realization of successful (engineered) systems" (INCOSE 2012). It focuses on holistically and concurrently discovering and understanding stakeholder needs; exploring opportunities; documenting requirements; and synthesizing, verifying, validating, deploying, sustaining and evolving solutions while considering the complete problem, from system concept exploration through system disposal.
- A systems engineer is "a person who practices systems engineering" as defined above, and whose systems engineering capabilities and experience include sustained practice, specialization, leadership, or authority over SE activities. These activities may be conducted by any competent person regardless of job title or professional affiliation.

Part 1 Articles

Articles in Part 1 include:

- Systems Engineering Overview
- Economic Value of Systems Engineering
- Systems Engineering: Historic and Future Challenges
- Systems Engineering and Other Disciplines
- Scope of the SEBoK
- Structure of the SEBoK
- SEBoK Users and Uses

Purpose of the SEBoK

The purpose of the SEBoK is to provide a widely accepted, community-based, and regularly updated baseline of SE knowledge. This baseline will strengthen the mutual understanding across the many disciplines involved in developing and operating systems. Shortfalls in such mutual understanding are a major source of system failures, which have increasingly severe impacts as systems become more global, interactive, and critical. Ongoing studies of system cost and schedule failures (Gruhl-Stutzke 2005; Johnson 2006) and safety failures (Leveson 2012) have shown that the failures have mostly come not from their domain disciplines, but from lack of adequate SE.

To provide a foundation for the desired mutual understanding, the SEBoK describes the boundaries, terminology, content, and structure of SE. In so doing, the SEBoK systematically and consistently supports six broad purposes, described in Table 1.

Table 1. SEBoK Purposes. (SEBoK Original)

	Purpose	Description
1	Inform Practice	Inform systems engineers about the boundaries, terminology, and structure of their discipline and point them to useful information needed to practice SE in any application domain.
2	Inform Research	Inform researchers about the limitations and gaps in current SE knowledge that should help guide their research agenda.
3	Inform Interactors	Inform performers in interacting disciplines (system implementation, project and enterprise management, other disciplines) and other stakeholders of the nature and value of SE.
4	Inform Curriculum Developers	Inform organizations defining the content that should be common in undergraduate and graduate programs in SE.
5	Inform Certifiers	Inform organizations certifying individuals as qualified to practice systems engineering.
6	Inform SE Staffing	Inform organizations and managers deciding which competencies that practicing systems engineers should possess in various roles ranging from apprentice to expert.

The SEBoK is a guide to the body of SE knowledge, not an attempt to capture that knowledge directly. It provides references to more detailed sources of knowledge, all of which are generally available to any interested reader. No proprietary information is referenced, but not all referenced material is free—for example, some books or standards must be purchased from their publishers. The criterion for including a source is simply that the authors believed it offered the best generally available information on a particular subject.

The SEBoK is global in applicability. Although SE is practiced differently from industry to industry and country to country, the SEBoK is written to be useful to systems engineers anywhere. The authors were chosen from diverse locales and industries, and have refined the SEBoK to broaden applicability based on extensive global reviews of several drafts.

The SEBoK aims to inform a wide variety of user communities about essential SE concepts and practices, in ways that can be tailored to different enterprises and activities while retaining greater commonality and consistency than would be possible without the SEBoK. Because the world in which SE is being applied is evolving and dynamic, the SEBoK is designed for easy, continuous updating as new sources of knowledge emerge.

Scope and Context of the SEBoK

The SEBoK is one of two complementary products. The other, which uses the content of the SEBoK to define a core body of knowledge (CorBoK) to be included in graduate SE curricula, is called the Graduate Reference Curriculum for Systems Engineering (GRCSE™). GRCSE is *not* a standard, but a reference curriculum to be tailored and extended to meet the objectives of each university's graduate program. (Pyster and Olwell et al. 2012) These products are being developed by the Body of Knowledge and Curriculum to Advance Systems Engineering (BKCASE) [1] project.

Most of the SEBoK (Parts 2 – 6) focuses on domain-independent information—that which is universal to systems engineering regardless of the domain in which it is applied. Part 7 includes examples from real projects. These illustrate the concepts discussed elsewhere in the SEBoK, while detailing considerations relevant to domains such as aerospace, medicine, and transportation.

SE in the context of engineered systems (ES) is the primary scope for the SEBoK, though general systems concepts are also discussed in Part 2. The SEBoK also covers considerations for the disciplines of software engineering and project management, which are strongly intertwined with the practice of SE (see Part 6).

The context of the SEBoK is elaborated in two agent-activity-artifact diagrams in Part 1.

One summarizes the SEBoK's definition by an international group of volunteer authors; its review by the SE community at large; its life cycle evolution management and support by the two primary international SE-related professional societies, the Institute of Electrical and Electronic Engineers (IEEE) and the International Council on Systems Engineering (INCOSE); and its use in derivative products and services by the community at large.

A second diagram summarizes the interactions among systems engineers, systems developers, and the environment of an engineered system, across its life cycle of system definition, development, evolution (production, utilization, and support) and retirement. These are elaborated in the discussion of the nature of systems and systems engineering in Part 2, and in the Life Cycle Models article in Part 3.

SEBoK Uses

The communities involved with SE include its various specialists, engineers from disciplines other than systems engineering, managers, researchers, and educators. This diversity means that there is no single best way to use the SEBoK. The SEBoK includes use cases that highlight ways that particular communities can draw upon the content of the SEBoK, identify articles of interest to those communities, and discuss primary users (those who use the SEBoK directly), and secondary users (those who use the SEBoK with assistance from a systems engineer). See the article SEBoK Users and Uses.

SEBoK Development

This is SEBoK v. 1.4 of the SEBoK, released on June 29, 2015. 11 development releases preceded this production release:

1. Version 0.25 on September 15, 2010
2. Version 0.5 on September 19, 2011
3. Version 0.75 on March 15, 2012
4. Version 1.0 on September 14, 2012
5. Version 1.0.1 on November 30, 2012
6. Version 1.1 on April 26, 2013
7. Version 1.1.1 on June 14, 2013
8. Version 1.1.2 on August 15, 2013
9. Version 1.2 on November 15, 2013
10. Version 1.3 on May 30, 2014
11. Version 1.3.1 on December 5, 2014
12. Version 1.3.2. on April 14, 2015
13. Version 1.4 on June 29, 2015

Version 0.25 was released as a PDF document for limited review. A total of 3135 comments were received on this document from 114 reviewers across 17 countries. The author team studied these comments with particular interest in feedback about content and about diversity within the community.

In January 2011, the authors agreed to move from a document-based SEBoK to a wiki-based SEBoK, and beginning with v. 0.5, the SEBOK has been available at www.sebokwiki.org [2]. Making the transition to a wiki provided three benefits:

1. easy worldwide access to the SEBoK;
2. more methods for search and navigation; and
3. a forum for community feedback alongside content that remains stable between versions.

For additional information, see the article on Acknowledgements and Release History.

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< Return to Table of Contents | Parent Article | Next Article >

SEBoK v. 1.4 released 29 June 2015

SEBoK Discussion

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If you would like to provide edits on this article, recommend new content, or make comments on the SEBoK as a whole, please see the SEBoK Sandbox [3].

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[1] http://www.bkcase.org/
[2] http://www.sebokwiki.org/
[3] http://www.sebokwiki.org/sandbox/

Systems Engineering Overview

Systems engineering (SE) is an interdisciplinary approach and means to enable the realization of successful systems. Successful systems must satisfy the needs of their customers, users and other stakeholders. This article provides an overview SE as discussed in the SEBoK and the relationship between SE and systems (for additional information on this, please see Part 2).

Systems Engineering

SE is an interdisciplinary approach and means to enable the realization of successful systems. Successful systems must satisfy the needs of its customers, users and other stakeholders. Some key elements of systems engineering are highlighted in Figure 1 and include:

- The principles and concepts that characterize a system, where a system is an interacting combination of system elements to accomplish a defined objective(s). The system interacts with its environment, which may include other systems, users, and the natural environment. The system elements that compose the system may include hardware, software, firmware, people, information, techniques, facilities, services, and other support elements.
- A systems engineer is a person or role who supports this interdisciplinary approach. In particular, the systems engineer often serves to elicit and translate customer needs into specifications that can be realized by the system development team.
- In order to help realize successful systems, the systems engineer supports a set of life cycle processes beginning early in conceptual design and continuing throughout the life cycle of the system through its manufacture, deployment, use and disposal. The systems engineer must analyze, specify, design, and verify the system to ensure that its functional, interface, performance, physical, and other quality characteristics, and cost are balanced to meet the needs of the system stakeholders.
- A systems engineer helps ensure the elements of the system fit together to accomplish the objectives of the whole, and ultimately satisfy the needs of the customers and other stakeholders who will acquire and use the system.

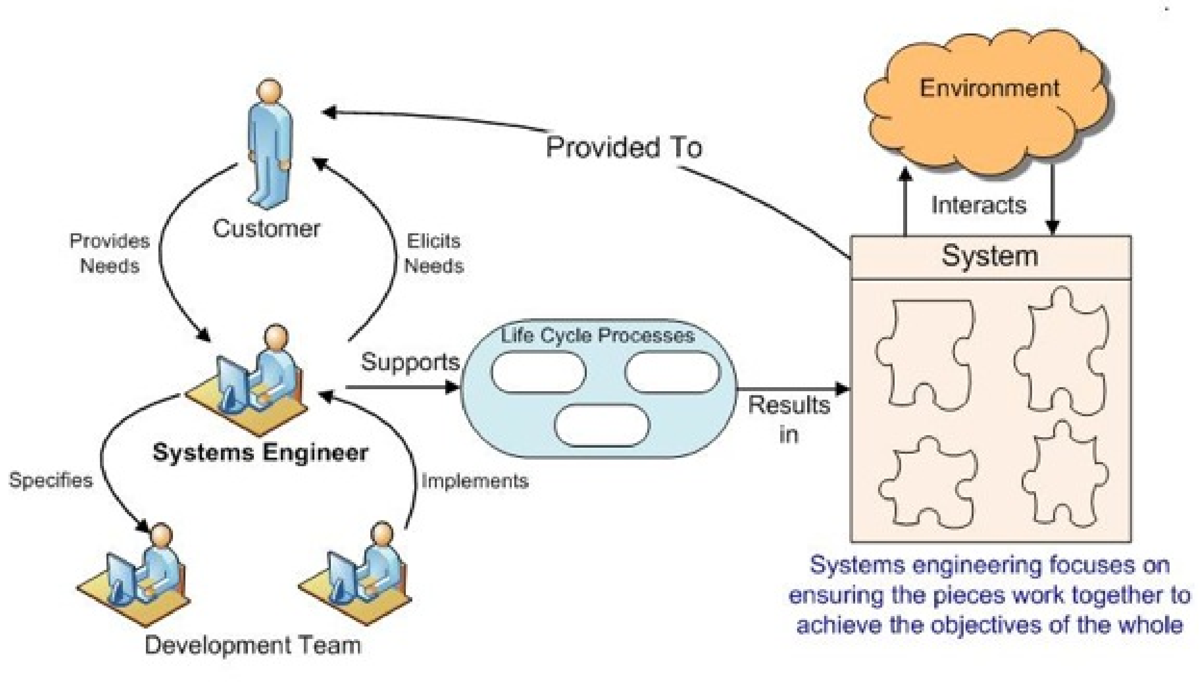

Figure 1. Key Elements of Systems Engineering. (SEBoK Original)

Systems and Systems Engineering

In the broad community, the term system "system," may mean an engineered system, a natural system, a social system, or all three. Since the province of SE is engineered systems, most SE literature assumes that this is the context. Thus, in an SE discussion, "system architecture" would refer to the architecture of the system being engineered (e.g., a spacecraft) and not the architecture of a natural system outside its boundary (e.g., the solar system).

This may produce ambiguities at times: for example, does "management" refer to management of the SE process, or management of the system being engineered? In such cases, the SEBoK tries to avoid misinterpretation by elaborating the alternatives into "system management" or "systems engineering management."

As with many special disciplines, SE uses terms in ways that may be unfamiliar outside the discipline. For example, in systems science and therefore SE, "open" means that a system is able to interact with its environment--as opposed to being "closed" to its environment. But in the broader engineering world we would read "open" to mean "non-proprietary" or "publicly agreed upon."

Some special meanings or terms reflect the historical evolution of SE. "Systems architecting" was introduced in (Rechtin 1991) to embody the idea that better systems resulted from concurrently rather than sequentially addressing a system's operational concept, requirements, structure, plans, and economics. "Soft SE" was introduced in (Checkland 1981) to express the criticality of human factors in SE. In both cases, the emphases that these terms imply are now accepted as integral to SE.

An extensive glossary of terms identifies how terms are used in the SEBoK, and shows how their meanings may vary in different contexts. As needed, the glossary includes pointers to articles providing more detail.

For more about the definition of systems, see the article What is a System? in Part 2. For more on SE see Part 3.

Scope of Systems Engineering within the Systems Domain

While considering all classes of systems, SE focuses on the domain of the engineered systems (ES). Sociotechnical systems are treated as a special form of engineered system. The differences and commonalities in scope of the three overall categories of systems — engineered, natural, and social — are depicted in Figure 2 below. (The figure is one of many possible versions of a Venn diagram where the underlined headings are always "natural systems", "engineered systems", and "social systems", while the bullet points listing instances of systems within and across those categories, could change with each new version.)

This picture provides a convenient tool for understanding the scope of an engineered system. For example, power generation and distribution systems are purely ESs which include software and human operators as well as hardware. Water and power safety legislation comes from the political processes of a legislature, which is a social system. The resulting water and power safety assurance and safety governance systems are sociotechnical systems whose participants work in both engineered systems and social systems.

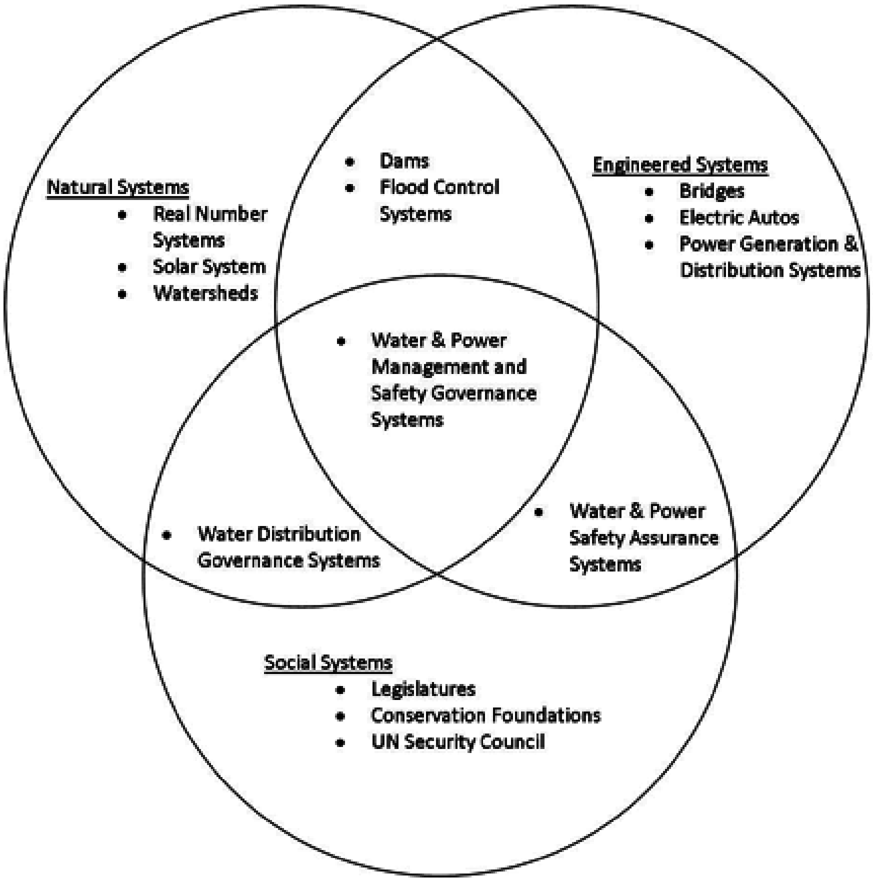

Figure 2. System Boundaries of Engineered Systems, Social Systems, and Natural Systems.
(SEBoK Original)

The nature of and relationships between these system domains is discussed in Part 2, which considers the general nature and purpose of systems and how these ideas are used to ensure a better ES. Part 2 covers:

- **Systems thinking** – a way of understanding complex situations by looking at them as combinations of systems
- **Systems science** – a collection of disciplines that have created useful knowledge by applying systems thinking and the scientific method to different aspects of the system domains
- **Systems approach** – a way of tackling real-world problems which uses the tools of system science to enable systems to be engineered and used.

One must understand both natural and sociotechnical systems to identify and scope the engineering of system problems or opportunities. This scoping largely determines whether engineered systems achieve their goals, without adverse impact on other outcomes, when those systems are deployed in the real world.

The primary focus of Part 3: Systems Engineering and Management, and Part 4: Applications of Systems Engineering is on how to create or change an engineered system to fulfill the goals of stakeholders within these wider system contexts. The knowledge in Part 5: Enabling Systems Engineering and Part 6: Systems Engineering and Other Disciplines examines the need for SE itself to be integrated and supported within the human activity systems in which it is performed, and the relationships between SE and other engineering and management disciplines.

Scope of Systems Engineering within the Engineered Systems Domain

The scope of SE does not encompass the entire ES domain. Activities can be part of the SE environment, but other than the specific management of the SE function, not considered to be part of SE. Examples include system construction, manufacturing, funding, and general management. This is reflected in the International Council on Systems Engineering (INCOSE) top-level definition of systems engineering as, "an interdisciplinary approach and means to enable the realization of successful systems." (INCOSE 2012) Although SE can *enable* the realization of a successful system, if an activity that is outside the scope of SE, such as manufacturing, is poorly managed and executed, SE cannot *ensure* a successful realization.

Again, a convenient way to define the scope of SE within the ES domain is to develop a Venn diagram. Figure 3 shows the relationship between SE, system implementation, and project/systems management. Activities, such as analyzing alternative methods for production, testing, and operations, are part of SE planning and analysis functions. Such activities as production line equipment ordering and installation, and its use in manufacturing, while still important SE environment considerations, stand outside the SE boundary. Note that as defined in Figure 3, system implementation engineering also includes the software production aspects of system implementation. Software engineering, then, is not considered a subset of SE.

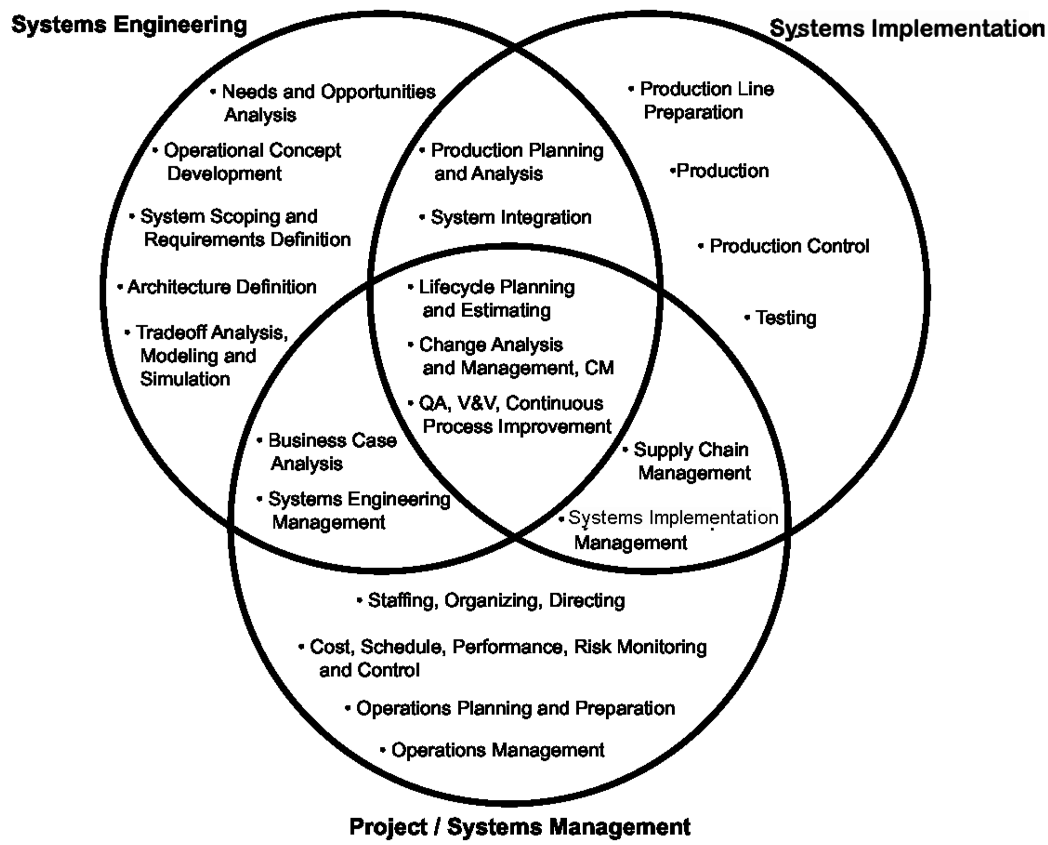

Figure 3. System Boundaries of Systems Engineering, Systems Implementation, and Project/Systems Management. (SEBoK Original)

Traditional definitions of SE have emphasized sequential performance of SE activities, e.g., "documenting requirements, then proceeding with design synthesis …". (INCOSE 2012) The SEBoK authors depart from tradition to emphasize the inevitable intertwining of system requirements definition and system design in the following revised definition of SE:

> *Systems Engineering (SE) is an interdisciplinary approach and means to enable the realization of successful systems. It focuses on holistically and concurrently understanding stakeholder needs;*

exploring opportunities; documenting requirements; and synthesizing, verifying, validating, and evolving solutions while considering the complete problem, from system concept exploration through system disposal. (INCOSE 2012, modified)

Part 3: Systems Engineering and Management, elaborates on the definition above to flesh out the scope of SE more fully.

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Additional References

None.

< Previous Article | Parent Article | Next Article >

SEBoK v. 1.4 released 29 June 2015

SEBoK Discussion

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Economic Value of Systems Engineering

The Increasing Value of Systems Engineering

With traditional projects, such as railroads, reservoirs, and refrigerators, a systems engineer faced a self-contained system that typically had relatively stable requirements, a sound scientific base, and numerous previous precedents. As most modern systems become parts within one or more evolving systems of systems (SoS), the performance of effective SE now takes on an ever-higher economic value, as the systems feature a rapidly increasing scale, dynamism, interdependence, human-intensiveness, sources of vulnerability, and novelty.

This is corroborated by the Case Studies and Vignettes in Part 7. Shortfalls in SE lead to either cancellation of already expensive systems or even more expensive systems in terms of total cost of ownership or loss of human life. Part 7 presents the problems in the United States Federal Aviation Administration (FAA) Advanced Automation System (AAS), United States Federal Bureau of Investigation (FBI) Virtual Case File System, the Hubble Space Telescope Case Study, and the Therac-25 medical linear accelerator.

On the other hand, the Global Positioning System (GPS), Miniature Seeker Technology Integration Project (MSTI), and Next Generation Medical Infusion Pump Project all demonstrate that investment in thorough SE results in highly cost-effective systems. Figure 1 summarizes the analyses data by Werner Gruhl, which relates investment levels in SE to cost overruns of the United States National Aeronautics and Space Administration (NASA) projects (Stutzke 2005). The results indicate that there is a general correlation between the amount invested in SE within a program and cost overruns, demonstrating the critical role of properly allocating SE resources.

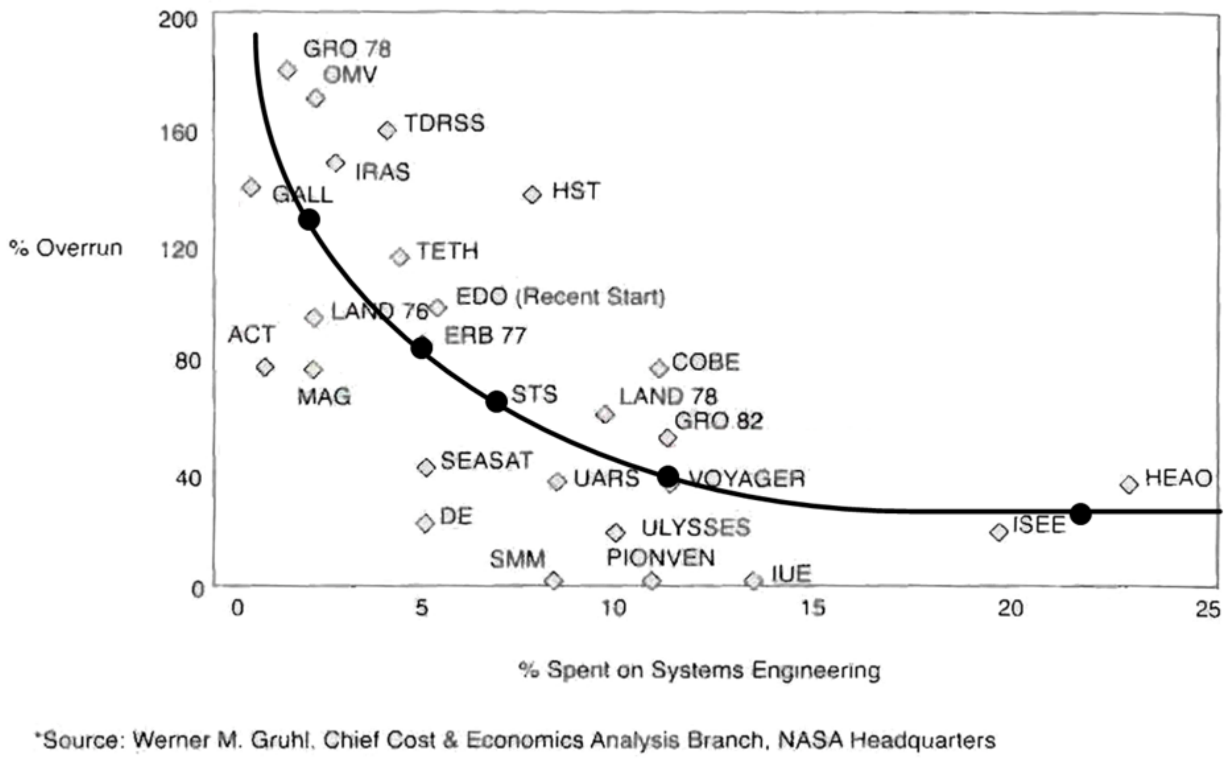

Figure 1. Relation of SE Investments to NASA Program Cost Overruns (Stutzke 2005). Released by NASA HDQRT/Gruhl.

Further Quantitative Evidence of the Value of Systems Engineering

Analysis of the effects of shortfalls in systems architecture and risk resolution (the results of insufficient SE) for software-intensive systems in the 161-project Constructive Cost Model II (COCOMO™ II) database, shows a statistically significant increase in rework costs as a function of project size measured in source lines of code (SLOC): averages of 18% rework for ten-thousand-SLOC projects and 91% rework for ten-million-SLOC projects. This data has influenced many major system projects to reconsider initial underinvestment in SE (e.g., Boehm et al. 2004), and well as to address "how much SE is enough" by balancing the risks of under-investing in SE against those of over-investing (often called "analysis paralysis"), as shown in Figure 2 (Boehm, Valerdi, and Honour 2008).

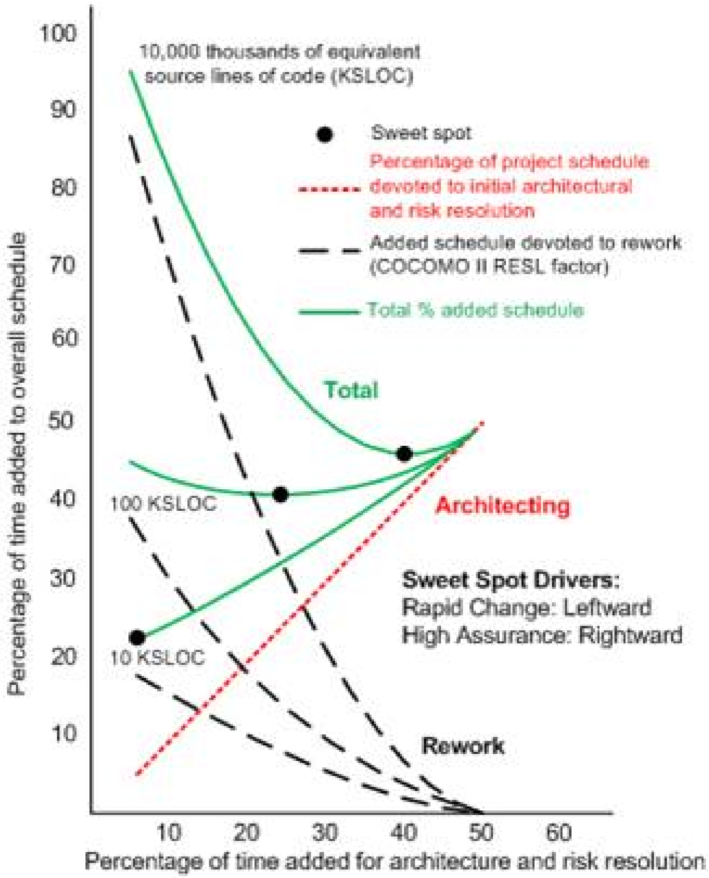

Figure 2. Risk-Balanced "How Much SE Is Enough" (Boehm, Valerdi, and Honour 2008). Reprinted with permission of John Wiley & Sons Inc. All other rights are reserved by the copyright owner.

Typically, small projects can quickly compensate for neglected SE interface definition and risk resolution; however, as projects grow larger and have more independently-developed components, the cost of late rework negates any savings in reduced SE effort. Additionally, medium-sized projects have relatively flat operating regions, while very large projects pay extremely large penalties for neglecting thorough SE. Extensive surveys and case study analyses corroborate these results.

Survey data on software cost and schedule overruns in *My Life Is Failure: 100 Things You Should Know to Be a Better Project Leader* (Johnson 2006) indicates that the primary sources of the roughly 50% of the commercial projects with serious "software overruns" are the result of shortfalls in SE (lack of user input, incomplete requirements, unrealistic expectations, unclear objectives, and unrealistic schedules). The extensive survey of 46 government-contracted industry projects conducted by the Software Engineering Institute (SEI)/National Defense Industrial Association (NDIA) illustrated a strong correlation between higher project SE capability and higher project performance (Elm et al. 2007). Ongoing research that combined project data and survey data reported in

“Toward an Understanding of The Value of SE” (Honour 2003) and “Effective Characterization Parameters for Measuring SE” (Honour 2010) has provided additional evidence as to the economic value of SE and further insights on critical factors the affect SE success.

A calibrated model for determining “how much SE is enough”, the Constructive Systems Engineering Cost Model (COSYSMO) has been developed and is discussed in (Valerdi 2008). It estimates the number of person-months that a project needs for SE as a function of system size (i.e., requirements, interfaces, algorithms, and operational scenarios), modified by 14 factors (i.e., requirements understanding, technology risk, personnel experience, etc.), which dictates the amount of SE effort needed. Other economic considerations of SE include the costs and benefits of reuse (Wang, Valerdi and Fortune 2010), the management of SE assets across product lines (Fortune and Valerdi 2013), the impact of SE on project risk (Madachy and Valerdi 2010), and the role of requirements volatility on SE effort (Pena and Valerdi 2010).

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Systems Engineering: Historic and Future Challenges

We can view the evolution of systems engineering (SE) in terms of challenges and responses. Humans have faced increasingly complex challenges and have had to think systematically and holistically in order to produce successful responses to challenges. From these responses, generalists have developed generic principles and practices for replicating success.

Historical Perspective

Some of the earliest relevant challenges were in organizing cities. Emerging cities relied on functions such as storing grain and emergency supplies, defending the stores and the city, supporting transportation and trade, afterlife preparations, providing a water supply, and accommodating palaces, citadels, and temples. The considerable holistic planning and organizational skills required to realize these functions were independently developed in the Middle East, Egypt, Asia, and Latin America, as described in Lewis Mumford's *The City in History* (Mumford 1961).

Megacities, and mobile cities for military operations, such as those present in the Roman Empire, emerged next, bringing another wave of challenges and responses. These also spawned generalists and their ideological works, such as Vitruvius and his *Ten Books on Architecture* (Vitruvius: Morgan transl. 1960). "Architecture" in Rome meant not just buildings, but also aqueducts, central heating, surveying, landscaping, and overall planning of cities.

The Industrial Revolution brought another wave of challenges and responses. In the nineteenth century, new holistic thinking and planning went into creating and sustaining transportation systems, including canal, railroad, and metropolitan transit. General treatises, such as *The Economic Theory of the Location of Railroads* (Wellington 1887), appeared in this period. The early twentieth century saw large-scale industrial enterprise engineering, such as the Ford automotive assembly plants, along with treatises like *The Principles of Scientific Management* (Taylor 1911).

The Second World War presented challenges around the complexities of real-time command and control of extremely large multinational land, sea, and air forces and their associated logistics and intelligence functions. The postwar period brought the Cold War and Russian space achievements. The U.S. and its allies responded to these challenges by investing heavily in researching and developing principles, methods, processes, and tools for military defense systems, complemented by initiatives addressing industrial and other governmental systems. Landmark results included the codification of operations research and SE in *Introduction to Operations Research* (Churchman et. al 1957), Warfield (1956), and Goode-Machol (1957) and the Rand Corporation approach as seen in *Efficiency in Government Through Systems Analysis* (McKean 1958). In theories of system behavior and SE, we see cybernetics (Weiner 1948), system dynamics (Forrester 1961), general systems theory (Bertalanffy 1968), and mathematical systems engineering theory (Wymore 1977).

Two further sources of challenge began to emerge in the 1960s, and accelerated in the 1970s through the 1990s: the growth of software functionality in systems, and, awareness of the criticality of the human element in complex systems.

While software was responsible for functionality in 8% of military aircraft in 1960, this number had risen to 80% in 2000 (Ferguson 2001). One response to this challenge is the appearance of model-based systems engineering (MBSE), which is better suited to managing complexity, including that of software, than traditional document-centric approaches (Friedenthal 2008).

Concerning awareness of the human element, the response was a reorientation from traditional SE toward "soft" SE approaches. Traditional hardware-oriented SE featured sequential processes, pre-specified requirements, functional-hierarchy architectures, mathematics-based solutions, and single-step system development. "Soft" SE is characterized by emergent requirements, concurrent definition of requirements and solutions, combinations of layered service-oriented and functional-hierarchy architectures, heuristics-based solutions, and evolutionary system development. Good examples are societal systems (Warfield 1976), soft systems methodology (Checkland 1981), and systems architecting (Rechtin 1991 and Rechtin-Maier 1997). As with Vitruvius, "architecting" in this sense is not confined to producing blueprints from requirements, but instead extends to concurrent work on operational concepts, requirements, structure, and life cycle planning.

Evolution of Systems Engineering Challenges

From 1990 on, rapidly increasing scale, dynamism, and vulnerabilities in the systems being engineered have presented ever-greater challenges. The Internet offers efficient interoperability of net-centric systems of systems (SoS), but brings new sources of system vulnerability and obsolescence as new Internet services (clouds, social networks, search engines, geolocation services, recommendation services, and electrical grid and industrial control systems) proliferate and compete with each other.

Meanwhile, challenges come from several ways in which solution approaches have proliferated:

- While domain-specific model-based approaches offer significant benefits, reconciling many different domain assumptions to get domain-specific systems to interoperate is a challenge.
- The appearance of many competing object-oriented methods posed a problem that was addressed by the development of the Unified Modeling Language (UML) (Booch-Rumbaugh-Jacobson 1998) and the Systems Modeling Language (SysML) (Friedenthal 2008). However, the wave of UML and SysML tools that followed, along with a number of alternative requirements and architecture representations intended to compensate for shortcomings of UML and SysML, again create dilemmas around interoperability and choice.
- Areas that have seen a sometimes bewildering growth of alternatives are: enterprise architecture, lean and agile processes, iterative and evolutionary processes, and methods for simultaneously achieving high-effectiveness, high-assurance, resilient, adaptive, and life cycle affordable systems.

This trend towards diversity has increased awareness that there is no one-size-fits-all product or process approach that works best in all situations. In turn, determining which SE approaches work best in which situation, and how to sustain workable complex SoSs containing different solution approaches, emerges as yet another challenge.

Similarly, assessing and integrating new technologies with increasing rates of change presents further SE challenges. This is happening in such areas as biotechnology, nanotechnology, and combinations of physical and biological entities, mobile networking, social network technology, cooperative autonomous agent technology, massively parallel data processing, cloud computing, and data mining technology.

Ambitious projects to create smart services, smart hospitals, energy grids, and cities are underway. These promise improved system capabilities and quality of life, but carry risks of reliance on immature technologies or on combinations of technologies with incompatible objectives or assumptions. The advantages of creating network-centric SoSs to “see first,” “understand first,” and “act first” are highly attractive in a globally competitive world, but carry challenges of managing complexes of hundreds of independently-evolving systems over which only partial control is possible. SE is increasingly needed but increasingly challenged in the quest to make future systems scalable, stable, adaptable, and humane.

To accommodate this complexity, the SEBoK presents alternative approaches along with current knowledge of where they work best. Being a wiki allows the SEBoK to evolve quickly while maintaining stability between versions.

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Systems Engineering and Other Disciplines

As discussed in the Scope of the SEBoK article, there are many touch points and overlaps between systems engineering (SE) and other disciplines. Systems engineers should have a basic understanding of the nature of these other disciplines, and often need to understand aspects of another discipline in detail. This article describes the landscape of disciplines that are intertwined with SE. For a closer view of the individual disciplines, see Part 6.

Engineering Disciplines Other than Systems Engineering

Engineering disciplines are mostly component-oriented and value-neutral in their intellectual content (Boehm and Jain 2006). Their underlying laws and equations, such as Ohm's Law, Hooke's Law, Newton's Laws, Maxwell's equations, the Navier-Stokes equations, Knuth's compendia of sorting and searching algorithms, and Fitts's Law of human movement, pertain to performance in a system-of-interest. They do not address how that performance contributes to the value propositions of stakeholders.

In contrast, SE is more holistic than component-oriented, and more stakeholder value-oriented than value-neutral, performance-oriented in its intellectual content. Realizing successful systems requires reasoning with stakeholders about the relative value of alternative realizations, and about the organization of components and people into a system that satisfies the often-conflicting value propositions of stakeholders. Stakeholders who are critical to the system's success include funders, owners, users, operators, maintainers, manufacturers, and safety and pollution regulators.

In some disciplines, the engineer evaluates and integrates design elements into a system that satisfies proxies of value. The wider the scope of the SoI, the broader the set of SE skills the engineer needs.

For example, an aeronautical engineer might integrate mechanical, electrical, fluid, combustion-chemical, software, and cockpit design elements into a system that satisfies proxies of value like flight range, payload capacity, fuel consumption, maneuverability, and cost of production and maintenance. In so doing, the engineer operates partly as a systems engineer. The SoI is the aircraft itself and the engineer applies aircraft-domain expertise.

However, the same engineer could participate in the engineering of passenger services, airport configurations, baggage handling, and local surface transportation options. All of these contribute to the value propositions of success-critical stakeholders. The SoIs are wider, and the engineer needs broader SE knowledge, skills, and abilities to operate as a systems engineer. The aircraft-domain expertise remains needed for effective engineering of the wider systems. As discussed in (Guest 1991), most good systems engineers are "T-shaped" people, with both a working knowledge of wider-system considerations, and a deep expertise in a relevant domain, such as aeronautical, manufacturing, software, or human factors engineering.

Engineering disciplines that are intertwined with SE include software engineering (SwE), human factors engineering, and industrial engineering. SwE and SE are not just allied disciplines, they are intimately intertwined (Boehm 1994). Most functionality of commercial and government systems is now implemented in software, and software plays a prominent or dominant role in differentiating competing systems in the marketplace. Software is usually prominent in modern systems architectures and is often the "glue" for integrating complex system components.

The scope of SwE includes both software SE and software construction, but does not include hardware SE. Thus neither SwE nor SE is a subset of the other. See Figure 1 in Scope of the SEBoK. For a definition of the relationship between the SEBoK and the *Guide to the Software Engineering Body of Knowledge (SWEBOK)*, which is published by the Institute of Electrical and Electronics Engineers (IEEE) (Abran et al. 2004) and is currently under revision, see Systems Engineering and Software Engineering.

Human factors engineering, from micro-ergonomics to macro-ergonomics, is intertwined with SE (Booher 2003; Pew and Mavor 2007). See Human Systems Integration in Part 6.

Industrial engineering overlaps significantly with SE in the industrial domain, but also includes manufacturing and other implementation activities outside of SE. See Systems Engineering and Industrial Engineering in Part 6.

Finally, to field a successful system, a systems engineer may need to know one or more of the many specialty fields in engineering, e.g., security, safety, reliability, availability, and maintainability engineering. Most of these are considered professional disciplines in their own right and many have their own bodies of knowledge. For explanations of how these disciplines relate to SE, overviews of what most systems engineers need to know about them, and references within their bodies of knowledge, see Systems Engineering and Specialty Engineering in Part 6.

Non-Engineering Disciplines

SE is intimately intertwined with two non-technical disciplines: technical management (TM), and procurement and acquisition (also known as acquisition and procurement). TM often falls within the purview of a systems engineer. Many SE textbooks, competency models, and university programs include material about TM. TM is a specialization of project management (PM). SE and PM have significant common content in TM, but neither is a subset of the other. See Figure 1 in the article Scope of the SEBoK. For a definition of the relationship between the SEBoK and the *Guide to the Project Management Body of Knowledge (PMBOK)*, which is published by the Project Management Institute (PMI) (PMI 2013), see Systems Engineering and Project Management in Part 6.

Procurement and acquisition practitioners draw upon SE to determine the scope and overall requirements of the system to be procured or acquired. They then prepare requests for proposals and statements of work, determine evaluation criteria, and design source selection processes. Once a leading source is selected, they decide upon contracting options that encompass payments, reviews, audits, incentive fees, acceptance criteria, procedures, and the nature of deliverables. Finally, they monitor progress with respect to plans (including those for SE), and negotiate and execute changes and corrective actions. Many of these activities amount to specialty disciplines within procurement and acquisition. See the article Related Disciplines in Part 6.

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Additional References

None.

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Scope of the SEBoK

The SEBoK is a large compendium of information about systems engineering. It:

- is a guide to the body of SE knowledge which provides references to detailed sources for additional information; it is not a self-contained knowledge resource
- is domain-independent, with implementation examples to provide domain-specific context
- focuses on engineered systems (ES), that is, products, services, enterprises, and systems of systems (SoS), while treating social and natural systems as relevant and important environmental considerations for ESs (see the discussion below for more on this as well as look at What is a System? in Part 2)
- recognizes that SE principles can be applied differently to different types of systems (see Part 4)
- provides resources for organization support of SE activities (see Part 5)
- explores the interaction between SE and other disciplines, highlighting what systems engineers need to know about these disciplines (see Part 6)

Each of these considerations depends upon the definition and scope of SE itself, which is the subject of the next section.

Systems Engineering and Engineered Systems Project Life Cycle Context

Figure 1 summarizes the main agents, activities, and artifacts involved in the life cycle of SE, in the context of a project to create and evolve an ES.

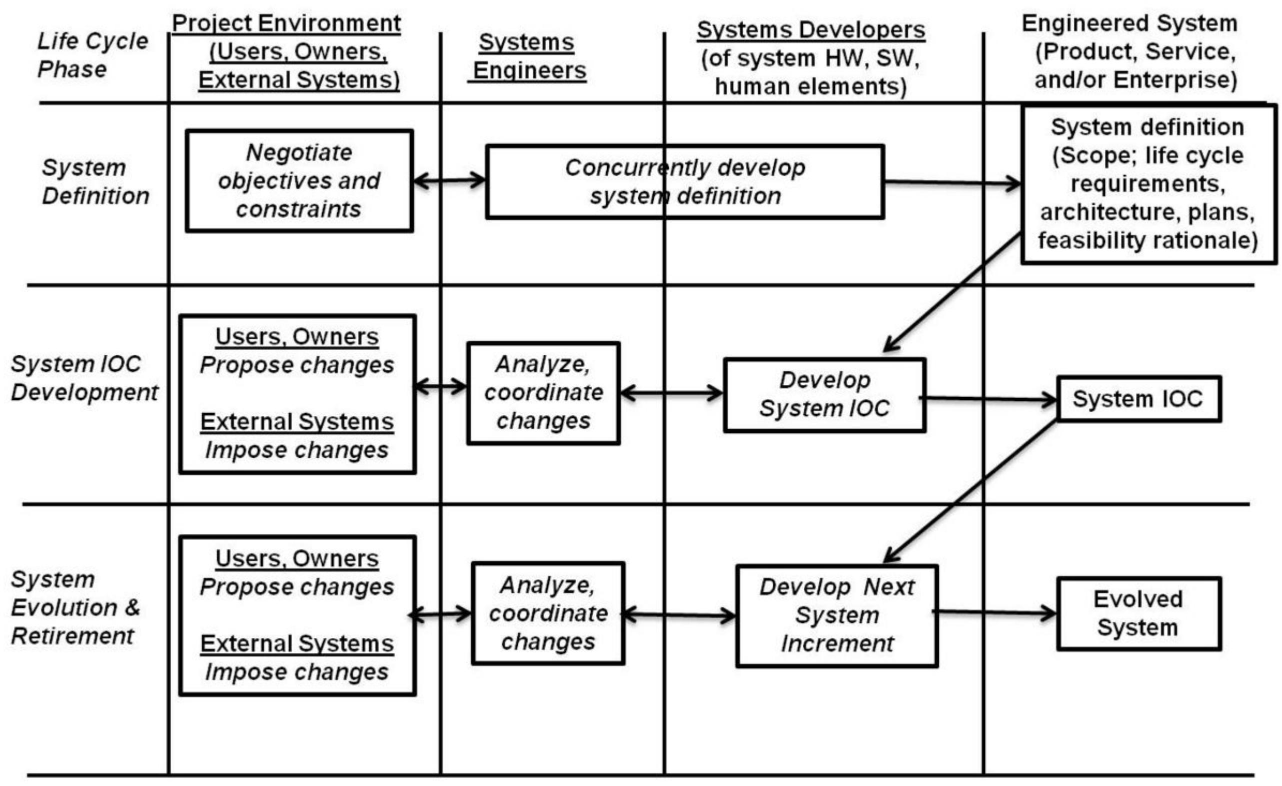

Figure 1. SE and Engineered System Project Life Cycle Context: Related Agents, Activities, and Artifacts. (SEBoK Original)

For each primary project life cycle phase, we see activities being performed by primary agents, changing the state of the ES.

- Primary project life cycle phases appear in the leftmost column. They are system definition, system initial operational capability (IOC) development, and system evolution and retirement.

- Primary agents appear in the three inner columns of the top row. They are systems engineers, systems developers, and primary project-external bodies (users, owners, external systems) which constitute the project environment.
- The ES, which appears in the rightmost column, may be a product, a service, and/or an enterprise.

In each row:

- boxes in each inner column show activities being performed by the agent listed in the top row of that column
- the resulting artifacts appears in the rightmost box.

Arrows indicate dependencies: an arrow from box A to box B means that the successful outcome of box B depends on the successful outcome of box A. Two-headed arrows indicate a two-way dependencies: an arrow that points both from box A to box B and from box B to box A means that the successful outcome of each box depends on the successful outcome of the other.

For example, consider how the inevitable changes that arise during system development and evolution are handled:

- One box shows that the system's users and owners may propose changes.
- The changes must be negotiated with the systems developers, who are shown in a second box.
- The negotiations are mediated by systems engineers, who are shown in a third box in between the first two.
- Since the proposed changes run from left to right and the counter-proposals run from right to left, all three boxes are connected by two-headed arrows. This reflects the two-way dependencies of the negotiation.

An agent-activity-artifact diagram like Figure 1 can be used to capture complex interactions. Taking a more detailed view of the present example demonstrates that:

- The system's users and owners (stakeholders) propose changes to respond to competitive threats or opportunities, or to adapt to changes imposed by independently evolving external systems, such as Commercial-off-the-Shelf COTS products, cloud services, or supply chain enablers.
- Negotiation among these stakeholders and the system developers follows, mediated by the SEs.
- The role of the SEs is to analyze the relative costs and benefits of alternative change proposals, and synthesize mutually satisfactory solutions.

SEBoK Domain Independent Context

The SEBoK uses language and concepts that are generally accepted for domain-independent SE. For example, the domain-independent conceptual foundations of SE are elaborated in Part 2: Foundations of Systems Engineering. However, each of the numerous domains in which SE is practiced — including telecommunications, finance, medicine, and aerospace — has its own specialized vocabulary and key concepts. Accordingly, the SEBoK is designed to show how its domain-independent material relates to individual domains, by means of examples that tell stories of how SE is applied in particular domains. (Part 7) consists of examples (case studies and vignettes), each set in a particular domain such as aerospace, medicine, or software, and featuring vocabulary and concepts special to that domain. There are similar vignettes in some of the Use Cases in Part 1. These examples demonstrate the effect of domain on the application of SE and complement the domain-independent information elsewhere in the SEBoK. They show how a concept works in a given domain and provide a fair opportunity for reviewers to reflect on whether there are better ways to capture application-dependent aspects of SE knowledge.

The authors recognize that case studies and vignettes add significant value to the SEBoK, and expect many more to be added as the SEBoK evolves.

SEBoK Life Cycle Context

Figure 2 summarizes the main agents, activities, and artifacts in the SEBoK life cycle.

The SEBoK is one of two complementary products. The other, which uses the content of the SEBoK to define a core body of knowledge (CorBoK) to be included in graduate SE curricula, is called the *Graduate Reference Curriculum for Systems Engineering (GRCSE)* (Pyster et al. 2012). GRCSE is not a standard, but a reference curriculum to be tailored and extended to meet the objectives of each university's graduate program. These products are being developed by the Body of Knowledge and Curriculum to Advance Systems Engineering (BKCASE) project (see http://www.bkcase.org).

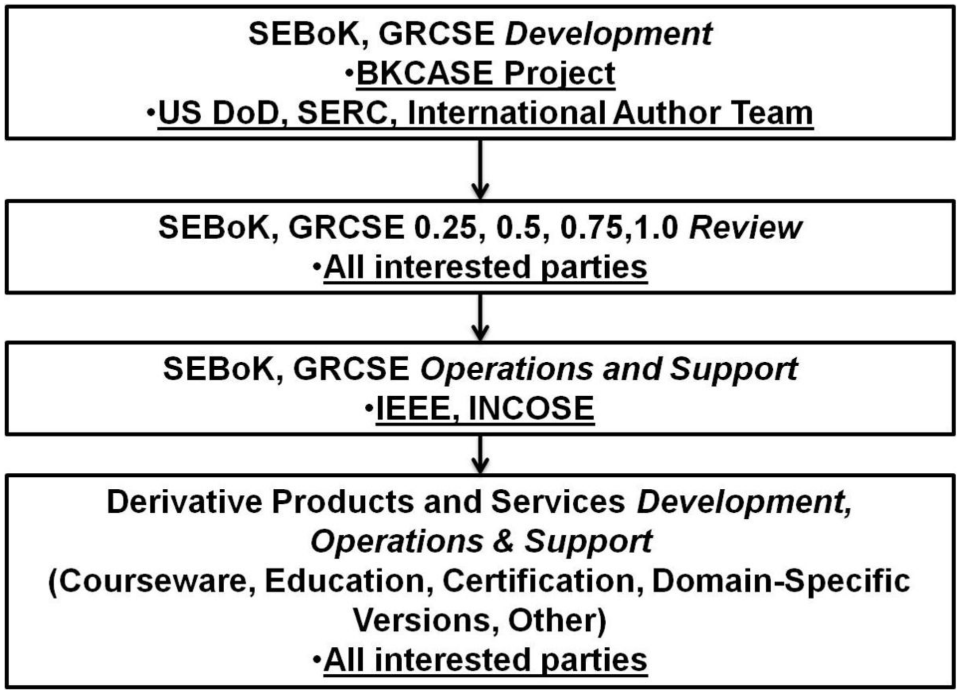

Figure 2. SEBoK Life Cycle and Context: Related Agents, Activities, and Artifacts. (SEBoK Original)

The BKCASE project, led by Stevens Institute of Technology and the Naval Postgraduate School, draws upon three primary resources. The U.S. Department of Defense (DoD) has provided the funding and a representative, but does has not constrain or direct the project's approach and content. The Systems Engineering Research Center (SERC), a DoD university-affiliated research center operated by Stevens Institute of Technology, supports BKCASE management and infrastructure and is the means by which DoD funding is delivered to the BKCASE project. The international author team of 70 members has been selected for expertise in SE and diversity of national origin (authors have come from 10 different countries in 5 continents), economic sector (government, industry, academia), and SE specialty area. These authors have donated their time to the development of the SEBoK content.

The SEBoK content has been developed incrementally. Each of the prototype versions (0.25, 0.5, and 0.75) underwent an open review by all interested parties. Over 200 reviewers submitted thousands of comments, each of which was adjudicated. Upon completion of the initial SEBoK and GRCSE development in late 2012, the Institute of Electrical and Electronic Engineers Computer Society (IEEE-CS) and the International Council on Systems Engineering (INCOSE), together with the SERC, are anticipated to become the primary stewards for both the SEBoK and the GRCSE. Interested parties will be able develop, operate, and support derivative products and services such as courseware, education, certification, and domain-specific versions of the SEBoK and the GRCSE. Copyright Information offers complete information about what others may do with the content of the SEBoK.

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Structure of the SEBoK

The SEBoK is divided into seven parts, the first six of which focus on domain-independent knowledge, and the seventh part devoted to implementation examples.

Structure

Part 1: SEBoK Introduction

To help you get the most out of the SEBoK, this part explains the scope, context, and structure of the SEBoK, and then turns to aspects of systems engineering (SE) itself that matter as you begin to use the SEBoK: SE's economic value, history, future, and relationship to other disciplines. An overview of who should use the SEBoK, and for what purpose, is followed by detailed use cases. This part concludes with a summary of how the SEBoK has evolved.

Part 2: Foundations of Systems Engineering

Stating what systems are, this part covers systems fundamentals and moves on to describe systems science in terms of history and major questions, systems thinking as a set of ideas to be used in SE, and how systems are represented with models. It concludes by looking at how to take a systems approach to an engineered system (ES), which leads naturally into the next two parts, which are concerned with SE management and applications.

Part 3: Systems Engineering and Management

How systems are engineered is the subject of this part, which begins with the life cycle models common in SE, then moves on to SE management, where planning, measurement, risk, and quality are among the topics. Next is product and service life management, a distinct area of SE management that emphasizes the entire life cycle including retirement and disposal. An account of SE standards concludes this part. Focused on what many think of as the main body of SE, including best practices and common pitfalls, this part constitutes a substantial proportion of the SEBoK. It is anticipated that this part and the following parts will reflect increased emphasis on model-based systems engineering (MBSE) practices as these practices continue to evolve and become more mainstream.

Part 4: Applications of Systems Engineering

This part covers how to apply SE principles as defined in the previous part, focusing on four major categories of systems in turn: products, services, enterprises, and systems of systems (SoS).

Part 5: Enabling Systems Engineering

The subject of this part is how to organize to perform SE activities, at the enterprise, team, or individual level. The range of considerations extends from value proposition, business purpose, and governance, down to competency, personal development as a systems engineer, and ethics.

Part 6: Related Disciplines

How SE is intertwined with software engineering (SwE), project management (PM), industrial engineering, procurement and acquisition, and specialty engineering, is the subject of this part, which describes the various system "–ilities" (like reliability, availability, and maintainability) that SE must balance and integrate.

Part 7: Systems Engineering Implementation Examples

A set of real-world examples of SE activities forms the natural conclusion of the SEBoK. These come in two forms: case studies, which refer the reader to and summarize published examinations of the successes and challenges of SE programs, and vignettes, which are brief, self-contained wiki articles. This part is a key place to look within the SEBoK for lessons learned, best practices, and patterns. Many links connect material in the examples to the conceptual, methodological, and other content elsewhere in the SEBoK.

Addenda

The SEBoK contains a Glossary of Terms, which provides authoritatively-referenced definitions of key terms. It also contains a list of Primary References, with additional information about each reference. Quicklinks in the left margin provide additional background information, including a table of contents, a listing of articles by topic [1], and a list of Acronyms.

Inter-relationships

As you navigate the SEBoK, it may be useful to consider the relationships among the elements of the SEBoK and those found in its external environment. Figures 1 and 2 from the article Scope and Context of the SEBoK express those relationships. These figures are an outgrowth of a systems modeling language (SysML) concept map whose development, application, and iteration were key activities when the SEBoK was being written.

References

None.

< Previous Article | Parent Article | Next Article >

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References

[1] http://sebokwiki.org/1.1.1/index.php?title=Category:Topic

SEBoK Users and Uses

The users and uses described in this article were identified based on the six SEBoK purposes described in the SEBoK Introduction.

Users can either be primary (those who use the SEBoK directly) or secondary (those who use the SEBoK with assistance from a systems engineer). Indicative, but not exhaustive, sets of example uses are shown in Tables 1 and 2 below.

New to SEBoK or Systems Engineering?

The list of users and use cases below allow someone who has come to the SEBoK with a particular focus to identify quickly where to focus their reading. If you are completely new to systems engineering or have no clear view of how it is covered in the SEBoK you should use Use Case 0 below to orient yourself and learn the basics before looking at the other use cases:

- Use Case 0: Systems Engineering Novices

Primary Users

Primary users are those who use the SEBoK directly, as shown in Table 1. Hyperlinks in the second column link to the associated use case, where one has been written. The use cases are listed at the end of the topic, and may also be seen here. [1]

Table 1. Primary SEBoK Users and Common Uses. (SEBoK Original)

#	Users	Uses
1	Practicing Systems Engineers ranging from novice through expert	• Taking on a new SE role in a project; preparing by finding references for study • Expanding SE expertise and specialization; preparing by finding references for study • Seeking to understand the principles of SE; seeking the best references to elaborate on those principles • Reviewing a project or mentoring a new SE performer; seeking to understand what best practices to look for • Pursuing professional development through study of SE topics, including new developments in SE
2	Process engineers responsible for defining or implementing SE processes	• Maintaining a library of SE process assets; seeking to understand which SE process models and standards are most relevant • Tailoring a process for a specific project; seeking to learn how others have tailored processes, or how a specific application domain affects tailoring • Measuring the effectiveness of an organization's SE processes; seeking to learn how others have done that • Defining standards for a professional society or standards organization
3	Faculty Members	• Developing a new graduate program in SE, and deciding what core knowledge all its students must master; the user should consult the *Graduate Reference Curriculum for Systems Engineering (GRCSE™)* in conjunction with the SEBoK • Developing a new SE course; seeking to identify course objectives, topics, and reading assignments • Incorporate SE concepts in courses or curricula focused on engineering disciplines other than SE
4	GRCSE authors	• As members of the GRCSE author team, deciding what knowledge to expect from all SE graduate students • See *Graduate Reference Curriculum for Systems Engineering (GRCSE™)* (Pyster et al. 2012)

5	Certifiers	• Defining a company's in-house SE certification program; seeking to understand what others have done, how such programs are typically structured, and how to select the knowledge that each person seeking certification should master • Defining certification criteria for a professional society or licensure program
6	General Managers, Other Engineers, developers, testers, researchers	• Mastering basic vocabulary, boundaries, and structure of SE; seeking a few primary references • Learning what the scope of SE is, relative to the General Manager role • Learning what the role of the systems engineer consists of, relative to others on a project or in an organization • Learning to effectively perform a general manager role on an SE integrated product team
7	Customers of Systems Engineering	• Providing resources to and receiving artifacts from systems engineers • Seeking to better understand what to ask for, how to request it, how much to pay for it, and how to judge the quality of what is received
8	SE managers	• Evaluating possible changes in team processes and tools proposed by systems engineers on various teams; seeking independent information with which to evaluate the proposals • Hiring systems engineers, and developing competency-based job descriptions
9	SE researchers	• Looking for gaps are in SE knowledge to help guide a research agenda • Getting familiarize with a research topic; seeking the most important articles about the topic

Secondary Users

Secondary users are those who use the SEBoK with assistance from a systems engineer, as shown in Table 2.

Table 2. Secondary SEBoK Users and Common Usages. (SEBoK Original)

#	Users	Uses
1	Human resource development professionals	• Supporting the hiring and professional development of systems engineers
2	Non-technical managers	• Augmenting understanding of central concerns with information about relevant SE topics; e.g., a contracting manager might want to better understand SE deliverables being called out in a contract
3	Attorneys, policy makers	• Defining the impact of SE performance on central concerns; e.g., understanding the liability of a systems engineer for errors in judgment on a project, or the limitations of SE in guaranteeing the success of a project against actions of sponsors, managers, or developers

List of Use Cases

At this time not every class of user has a use case developed. To illustrate the major uses, the following use cases are included:

- Use Case 1: Practicing Systems Engineers. This covers the first set of users from Table 1.
- Use Case 2: Other Engineers. This covers the second and sixth sets of users from Table 1.
- Use Case 3: Customers of Systems Engineering. This covers the seventh set of users from Table 1.
- Use Case 4: Educators and Researchers. This covers the third, fourth, and ninth sets of users from Table 1.
- Use Case 5: General Managers. This covers the sixth and eighth sets of users from Table 1.

While not exhaustive, the use cases show the utility of the SEBoK in various applications and contexts.

References

None.

< Previous Article | Parent Article | Next Article >

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References

[1] http://sebokwiki.org/draft/Case_Studies

Use Case 0: Systems Engineering Novices

Some users of the Systems Engineering Body of Knowledge (SEBoK) may be new to the field. This article provides recommended readings for such a user.

Learn the Basic Terms

As discussed in the Introduction to the SEBoK, there are four key terms that you should first understand when learning about systems engineering (SE):

- A system is "a collection of elements and a collection of inter-relationships amongst the elements such that they can be viewed as a bounded whole relative to the elements around them. Open Systems exists in an environment described by related systems with which they may interact and conditions to which they may respond. While there are many definitions of the word "system," the SEBoK authors believe that this definition encompasses most of those which are relevant to SE.
- An engineered system is an open system of technical or sociotechnical elements that exhibits emergent properties not exhibited by its individual elements. It is created by and for people; has a purpose, with multiple views; satisfies key stakeholders' value propositions; has a life cycle and evolution dynamics; has a boundary and an external environment; and is part of a system-of-interest hierarchy.
- Systems engineering is "an interdisciplinary approach and means to enable the realization of successful (engineered) systems". It focuses on holistically and concurrently understanding stakeholder needs; exploring opportunities; documenting requirements; and synthesizing, verifying, validating, and evolving solutions while considering the complete problem, from system concept exploration through system disposal.
- A systems engineer is "a person who practices systems engineering" as defined above, and whose systems engineering capabilities and experience include sustained practice, specialization, leadership, or authority over SE activities. These activities may be conducted by any competent person regardless of job title or professional affiliation.

Get an Overview

The next step for someone new to SE is get an overview of the discipline. Part 1: SEBoK Introduction contains four articles particularly helpful to one new to SE.

- The article Systems Engineering Overview frames systems engineering inside the larger topic of 'Systems Science.'
- The article Economic Value of Systems Engineering makes the business case for investing in systems engineering as a way to reduce total ownership cost.
- The article Systems Engineering and Other Disciplines discusses briefly how systems engineers and other engineers interact as together they develop complex systems.
- Finally, the article Systems Engineering: Historic and Future Challenges gives a quick history of the discipline and discusses what lays ahead.

Learn about Systems

Engineering is often described as the application of science to develop new products or systems. Part 2: Foundations of Systems Engineering describes some of the underlying systems principles that form the foundation for systems engineering.

- The Knowledge Area on Systems Fundamentals contains five articles. What is a System? is recommended for a new user.
- The Knowledge Area on Systems Science presents two articles on its history and approaches. Both are recommended.
- The Knowledge Area on Systems Thinking has four articles. The first, What is Systems Thinking?, is recommended on a first reading.
- One of the most important current research and practice areas of SE is Model Based Systems Engineering (MBSE). The Knowledge Area Representing Systems with Models provides the foundation for MBSE. The first three of the five articles in the KA are recommended.

Learn how the Systems Approach is Applied to Engineered Systems

The Knowledge Area Systems Approach Applied to Engineered Systems describes how systems science and systems thinking lead to the practice of systems engineering. All eight articles are recommended.

- Overview of the Systems Approach
- Engineered System Context
- Identifying and Understanding Problems and Opportunities
- Synthesizing Possible Solutions
- Analysis and Selection between Alternative Solutions
- Implementing and Proving a Solution
- Deploying, Using, and Sustaining Systems to Solve Problems
- Stakeholder Responsibility
- Applying the Systems Approach

Explore the Methods of Systems Engineering

The SEBoK uses a life-cycle framework to describe the processes that comprise systems engineering. Part 3: SE and Management contains the plurality of the content of the SEBoK in eight knowledge areas. A new user should be familiar with the introductions to each of these Knowledge Areas, and should read further in those KAs of interest.

- Life Cycle Models
- Concept Definition
- System Definition
- System Realization
- System Deployment and Use
- Systems Engineering Management
- Product and Service Life Management
- Systems Engineering Standards

Explore the Applications of Systems Engineering

The SEBoK partitions the body of knowledge between methods and areas of application. Areas of application are classified as:

- Product Systems Engineering
- Service Systems Engineering
- Enterprise Systems Engineering
- Systems of Systems (SoS)

A new user should read the introduction to Part 4: Applications of Systems Engineering and to the four knowledge areas listed above. The reader's interests can then suggest which further reading should be done.

Read Case Studies

Finally, the new user should scan the case studies and vignettes in Part7: SE Implementation Examples and read a few of those in areas that appeal to the reader. This will help reinforce the fundamentals as well as illustrate the practice of SE.

The following case studies are included:

- Successful Business Transformation within a Russian Information Technology Company
- Federal Aviation Administration Next Generation Air Transportation System
- How Lack of Information Sharing Jeopardized the NASA/ESA Cassini/Huygens Mission to Saturn
- Hubble Space Telescope Case Study
- Global Positioning System Case Study
- Medical Radiation Case Study
- FBI Virtual Case File System Case Study
- MSTI Case Study
- Next Generation Medical Infusion Pump Case Study

For Later Reading

Part 6: Related Disciplines contains a broad selection of Knowledge Areas and Topics that describe how systems engineers work with other disciplines. The Knowledge area on SE and Software Engineering is particularly important, as modern systems get much of their functionality from software.

Part 5: Enabling Systems Engineering has KAs describing how individuals, teams, and organizations can develop to practice effective systems engineering.

A person new to SE should become familiar with several references that are beyond that SEBoK. They include the INCOSE Handbook, several standards (listed in Relevant Standards), and the main journals of systems engineering (including but not limited to *Systems Engineering*, the *Journal of Enterprise Transformation*, and *Systems, Man, and Cybernetics*).

References

Works Cited

None.

Primary References

None.

Additional References

None.

Previous Article | Parent Article | Next Article >

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Use Case 1: Practicing Systems Engineers

Both for the entry-level systems engineer learning the discipline of systems engineering (SE), and the more experienced systems engineer seeking the knowledge required to accomplish a work activity, the SEBoK serves as a primary information source and a quick, comprehensive reference for SE information.

What these system engineers find in the SEBoK includes:

- definitions of terms,
- explanations of basic concepts and principles,
- useful discussions of topics,
- references to articles and textbooks that cover topics in-depth, and
- pointers to additional sources.

How Systems Engineers Use Topics

Researching SE-related subjects, identifying educational resources, and connecting with individuals or organizations which offer specialized expertise are all part of the job for the practicing systems engineer. The time available to the SE for these activities can be quite limited. The SEBoK is designed to ease the pressure on the systems engineer in this situation, in several ways:

- Because its content is based on research, proven practices, and emerging knowledge, the SEBoK makes high-quality information available to the systems engineer right away.
- Being composed of articles of 2000 words or less in most cases, the SEBoK enables the systems engineer to quickly get an overview of relevant topics.
- By providing primary references, each topic offers a direct route to more detailed information.
- Even greater detail, breadth, and a sense of what's relevant in the SE literature are available through the additional references each topic provides.
- Since the SEBoK sources have been reviewed and vetted by a team of experts, the SEBoK helps the systems engineer avoid less reliable information which can be hard to eliminate within Internet search results.
- The systems engineer who needs to connect with educators and researchers can find relevant names and institutions in SEBoK topics and references.

Systems engineers using the SEBoK may choose one or more of several approaches:

- searching on keywords or article names, using the text field, Search [1] button, and Go [2] button at the top right of each SEBoK page
- scanning the Quick Links, Outline (where the table of contents is located), or Navigation indexes that appear at the left of each SEBoK page, and following links from there to articles that seem likely to be of interest
- searching on keywords using an Internet search engine
- reading through one or more of Parts 1 through 7 in sequence

Reading the SEBoK in sequence is especially suitable for the practicing engineer who is new to SE, or is enrolled in an SE-related training course. For this engineer, SE (or some aspect of it) is a subject to be learned comprehensively. This is made easier by navigation links from each article to the previous, next, and parent articles as found in the Table of Contents.

For practicing systems engineers, having the SEBoK makes it possible to gain knowledge more quickly and reliably than they would otherwise. The goal is to spend less time searching for and compiling new information from disparate sources and more time getting work done.

For a team of practicing engineers, the gap in knowledge between more- and less-experienced engineers can be a major obstacle. The SEBoK serves as a tool for the team to build a framework of agreed-upon definitions and perspectives. The consistency of such a framework enhances communication across the team. New teams, especially, can benefit from bridging the gap between legacy and more-recently-acquired knowledge. For more information, see Enabling Teams in Part 5.

How Systems Engineers Use Implementation Examples

The SEBoK is written, for the most part, independent of any particular domain of practice. By design, parts 1 though 6 focus on the discipline of SE and not the numerous domains where SE can be applied.

This lack of domain-specific content is partly offset by Part 7, Systems Engineering Implementation Examples, which consists of case studies and vignettes drawn from a number of domains where SE is applied. Each example demonstrates the impact of a particular application domain upon SE activities. Examples are generally most useful to the systems engineer when they are aligned with the domain in which the he or she is working, but sometimes ideas from an example in one domain can be usefully applied to situations in another.

Example: Model-Based Systems Engineering Practitioners

For practitioners of model-based systems engineering (MBSE), the Representing Systems with Models knowledge area is of central importance within the SEBoK.

Academic faculty who use the SEBoK to support curriculum development and assessment can refer to the same knowledge area to ensure that their curricula accurately cover the languages and/or methodologies such as System Modeling Language (SysML) and Object-Process Methodology (OPM).

SE researchers, too, can adopt an MBSE approach, making their research products more formal and rigorous by basing them on models.

In MBSE, models of systems support system life cycle activities, including requirements engineering, high-level architecture, detailed design, testing, usage, maintenance, and disposal.

Vignette: Systems Engineering for Medical Devices

Tara Washington has worked as a engineer for the HealthTech medical device company for seven years. Besides continuing to improve her strong software skills, she has shown an aptitude for systems thinking. To better understand the products that her software supports, Tara has taken courses in electrical engineering, mechanical engineering, and physiology. The coursework has helped her to perform effectively as a software system analyst on the SE teams of her last two projects.

HealthTech’s Research Division proposes a new concept for a highly programmable radiation therapy device that monitors the effects of the radiation on various parts of the body and adjusts the parameters of the radiation dosage to maximize its effectiveness, subject to a number of safety constraints. The software-intensiveness of the device leads Tara’s project manager to recommend her as the lead systems engineer for the design and development of the product.

Tara welcomes the opportunity, knowing that she possesses enough domain knowledge to take the lead SE role. Even so, she realizes that she has picked up SE skills mainly by intuition and needs to build them up more systematically. Tara begins to consult some of HealthTech’s lead systems engineers, and to study the SEBoK.

After reading the SEBoK Introduction, Tara feels that she has a solid overview of the SEBoK. Tara finds that the next topic, Scope and Context of the SEBoK, outlines the key activities that she expects to lead, along with others which will require her to collaborate with systems developers and project and systems management personnel.

The same topic identifies those parts of the SEBoK that Tara needs to study in preparation for her lead systems engineer role:

- SE concepts, principles, and modeling approaches in Part 2 (Representing Systems with Models knowledge area (KA))

- life cycle processes, management, technical practices, in Part 3 (Systems Engineering and Management KA)
- approaches for specifying, architecting, verifying and validating the hardware, software, and human factors aspects of the product, as well as common pitfalls to avoid and risks to manage, also in Systems Engineering and Management
- guidelines for the systems engineering of products, in Part 4: Applications of Systems Engineering, including references
- SE knowledge, skills, abilities, and attitudes (KSAAs) needed for a project in Part 5: Enabling Systems Engineering including references
- specialty engineering disciplines that may be key to the project's success, in Part 6: Related Disciplines

Tara's awareness of the deaths caused by the Therac-25 radiation therapy device motivates her to study not only the Safety Engineering topic in Part 6, but all of its key references as well.

While reading about SE life cycle process models in Systems Engineering and Management in Part 3, Tara notes the reference to the Next Generation Medical Infusion Pump Case Study in Part 7. This case study strikes Tara as highly relevant to her medical-device work, and she observes that it is organized into phases similar to those used at HealthTech. From the case study, Tara gains understanding of how a project such as hers would progress: by concurrently evaluating technology opportunities, by discovering the needs of various device stakeholders such as patients, nurses, doctors, hospital administrators, and regulatory agencies, and by working through increasingly detailed prototypes, specifications, designs, plans, business cases, and product safety analyses.

The case study mentions its source: Human-System Integration in the System Development Process [3] (Pew and Mavor 2007), published by the U.S. National Research Council. Tara obtains this book. In it, she finds numerous good practices for human-systems needs analysis, organizational analysis, operations analysis, prototyping, usability criteria formulation, hardware-software-human factors integration, process decision milestone review criteria, and risk management.

As a result of her SEBoK-based study, Tara feels better-qualified to plan, staff, organize, control, and direct the SE portion of the HealthTech radiation therapy device project and to help bring the project to a successful conclusion.

Summary

In the SEBoK, practicing engineers have an authoritative knowledge resource that can be accessed quickly to gain essential high-level information, and to identify the best references for in-depth study and research into SE topics when an individual's initial level of understanding is not adequate to get the job done.

The SEBoK is also a resource for practicing engineers who teach, as well as those taking training courses.

References

Works Cited

Pew, R. and A. Mavor. 2007. *Human-System Integration in the System Development Process: A New Look.* Washington, DC, USA: The National Academies Press.

Primary References

None.

Additional References

None.

< Previous Article | Parent Article | Next Article >

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[1] http://www.mediawiki.org/wiki/Help:Searching
[2] http://meta.wikimedia.org/wiki/Help:Go_button
[3] http://www.nap.edu/catalog.php?record_id=11893

Use Case 2: Other Engineers

The realization of successful complex systems requires experts from many disciplines to work together. This makes the SEBoK useful to engineers with backgrounds in biomedical, civil, electrical, chemical, civil, materials, mechanical, software, and many other engineering disciplines.

Studying the SEBoK enables engineers from disciplines other than systems engineering (SE) to

- see why good systems engineering practice must involve multiple disciplines,
- appreciate a broader view of systems beyond their specialties,
- understand how their contributions fit into the larger systems picture, and
- prepare to solve more difficult and encompassing problems.

In many cases, engineers who study systems engineering as a supplement to their area of specialization find their professional value enhanced when they put the new knowledge into practice.

Use of Topics

For engineers from non-SE backgrounds, each part of the SEBoK contributes something to the experience of learning about systems engineering.

- Part 1 provides an overview both of systems engineering and of the SEBoK itself
- Part 2 highlights the areas of systems knowledge most relevant to systems engineering, providing a foundation for the theory and practice of systems engineering as explained in Parts 3, 4 and 5
- Part 3 includes the knowledge areas of Life Cycle Models, System Definition, System Realization, and System Deployment and Use, all highly important when approaching study of SE from another discipline.
  - Also in Part 3, Systems Engineering Management includes such relevant topics as risk management, measurement, configuration management, and quality management.
- Part 4 identifies the SE activities for four kinds of engineered systems, namely products, services, enterprises, and systems of systems (SoS).
  - The primary references and glossary terms — not just the content — for a given type of system are essential reading for an engineer developing or modifying a system of that kind.
- Part 5, especially Team Capability, explains how systems engineers and other types of engineers fit into the larger picture of enabling individuals and teams to perform systems engineering activities, and into the larger picture of systems engineering organizational strategies.
- Part 6 is key for engineers from non-SE backgrounds.
  - Within Part 6, Systems Engineering and Project Management should be of interest to almost all readers, while Systems Engineering and Software Engineering and Systems Engineering and Specialty Engineering are naturally most essential for engineers in the respective disciplines.
- Part 7 illustrates how systems engineering practices, principles, and concepts are applied in real settings, and contains much universally-useful insight

Engineers may be tempted to skip over knowledge areas or topics which sound more like management than engineering stories, for example Systems Engineering Management in Part 3 or Part 5. This temptation should be resisted, because these topics are actually about how SE orchestrates the efforts of multiple disciplines, not management in the administrative sense.

Finally, the extensive lists of references throughout the SEBoK provide a basis for further readings.

Vignette: Software Engineer

Jose Wilks is an entrepreneurial software engineer who wants to learn more about systems engineering principles applied to embedded systems for advanced document identification and verification. He wants to implement best practices in developing highly secure systems for real-time image processing and forensic verification of documents. His company provides a rapid, secure and cost-effective solution for verifying the authenticity of identification, travel, and financial documents, with technology that runs on proprietary tablet computers for portable and fixed locations.

Jose is knowledgeable about computer hardware engineering, low-level interfaces between hardware and software, and the related tradeoffs in embedded devices. His company has developed research prototypes, but without the stringent security requirements for actual field usage linked to government identification databases. The few experimental units which have been sold have fared well in limited testing, but Jose wants to expand into markets for government agencies, law enforcement departments and the private sector. To make headway into those diverse markets, he will need to confront abundant new constraints and challenges.

Jose begins his study of SE by skimming the SEBoK Introduction and the Scope and Context of the SEBoK to get an overview of the SEBoK contents. As he reads, he sometimes refers to the *Software Engineering Body of Knowledge ((SWEBoK)* [1]*)* (Abran et al. 2004), which Jose already knows from his many years of experience on software projects. In the SEBoK, Jose is looking for nuggets of knowledge and pointers that can help his enterprise expand. Here are his notes:

- Part 3: Systems Engineering and Management has concepts that are new to us and that may work. Extra system-level verification and validation (V&V) gates identified in Life Cycle Models can be incorporated in company processes, and the references can help with implementation details. There is also material about system-wide procedures beyond software V&V, and about where to find testing and regulation standards used by various government entities. Together with the traditional software testing already in place, these processes could ensure conformity to the regulations and expedite the product's approval for use.
- Though the system concept is proven, the company must still convince potential buyers of the system's financial benefits while demonstrating that all security criteria are satisfied. To do that, we must understand the needs of the stakeholders better. In expressing system requirements and benefits, we need to start using the terminology of users, corporate/government purchasers, and regulatory agencies. Stakeholder Needs and Requirements is relevant here. The company needs to quantify expected return on investment (ROI) for its products.
- System Realization addresses our broader V&V concerns. We need to demonstrate the measures we are taking to boost reliability of system performance. The standard models and measures for system reliability described in the SEBoK are new to us — now staff must develop tests to quantify important attributes. We may want to model reliability and system adherence to regulations using a form of model-based systems engineering (MBSE). We can learn more about this from the references.
- Systems Engineering Management makes it clear that new configuration management (CM) and information management (IM) procedures need to be adopted for federal database controls and integrity. We can use the references in Systems Engineering Standards to learn how to define processes and develop test cases.
- Part 5: Enabling Systems Engineering makes a convincing case that having the right people for a new systems engineering culture is critical. We should probably hire a systems engineer or two to augment our engineering department expertise.
- Our application must deal with private data concerns, and Part 7: Systems Engineering Implementation Examples, the FBI Virtual Case File System Case Study could help us avoid pitfalls that have hurt others in similar situations. We can put this in context based on Security Engineering in Part 6: Related Disciplines, and then follow up with further study based on the references.

Now Jose feels that he is better prepared to adapt his processes for new system lifecycles and environments, and that he can see a clear path through the morass of agencies and regulations. His priorities are to quantify the value proposition for his technology innovations, make inroads into new markets, and strengthen his staff for the long-term enterprise.

Vignette: Mechanical Engineer

Cindy Glass is a mechanical engineer whose experience in the petroleum industry has focused on large-scale oil extraction equipment in the field. Now Cindy is tasked with helping to manage the development of new offshore oil platforms featuring robotic technology and computer networks. This calls for incorporating SE principles from day one to cope with the systems considerations, which are broader than anything in Cindy's previous experience.

Some of the drilling is to be done with remote-controlled, unmanned underwater vehicles (UUVs). Along with safety, which was always a major concern, cybersecurity now takes center stage. Hostile state actors, “hacktivists,” or others could cause havoc if they succeed in taking control of the remote vehicles or other infrastructure. Unfortunately, software system implementation is completely new to Cindy, who realizes that this entails dealing with many more engineering disciplines and dimensions of system constraints than she previously encountered.

Cindy is accustomed to implementing minor design changes in existing equipment, with automation and safety guidelines already in place. Now she is starting from scratch, with the earliest stages of the platform lifecycle. While Cindy understands tradeoffs involving mechanical sub-systems like rigs and drilling materials, she now must now broaden her system analysis to include new environmental constraints and system security.

Cindy consults the SEBoK and discovers that for her effort to understand system design with many "-ilities," System Realization is a good starting point and its references should provide the in-depth information she needs.

The project lifecycle requires pursuing several major activities concurrently:

- engineering platform sub-components
- evaluating technology opportunities
- understanding the needs of all stakeholders inside and outside the company
- progressing through increasingly detailed prototypes, working slices of software, system specifications, designs, plans, business cases, and, security and safety analyses of the platform architecture and its operations.

To understand how to manage such a project lifecycle, Cindy turns to Part 3: Systems Engineering and Management. The planning section provides detailed advice for starting out. Cindy expects to conduct her management activities on a rigorous basis, to consider the interfaces between the engineering specialties, and to produce a project plan that calls for a broad set of integrated management and technical plans.

Being new to the software development world, Cindy reads The Nature of Software and Key Points a Systems Engineer Needs to Know about Software Engineering, and consults the SWEBoK [1] for references on software engineering. For guidance on managing a software team, she studies Key Points a Systems Engineer Needs to Know about Managing a Software Team.

These readings show Cindy how closely systems engineering and software engineering are intertwined. For example, they remind her to include security specialists at both the software level and the systems level from the beginning.

From her initial plunge into study of the SEBoK, Cindy has gained an appreciation of the wide range of system constraints she must account for, and the many engineering disciplines she must work with as a result. She plans to consult the references in the SEBoK on each unfamiliar subject that she encounters throughout the architecting, design, development and deployment of the new platforms.

Summary

Engineers from disciplines other than systems engineering benefit from the insights about SE principles that the SEBoK provides. Studying the knowledge areas highlighted in this use case and the sources to which their references point can help such engineers become more interdisciplinary. Ultimately, they can consider broadening their work responsibilities, rendering them more valuable to their employers and society.

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Primary References

None.

Additional References

None.

< Previous Article | Parent Article | Next Article >

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[1] http://www.computer.org/portal/web/swebok

Use Case 3: Customers of Systems Engineering

Customers of systems engineering (SE) provide resources to SE organizations and individuals, and receive SE products and services in return. They are among the stakeholders for a system-of-interest (SoI). They and other stakeholders express needs and expectations for results that system engineers provide.

Although their main SE activity is helping to define the system, customers must take account of all life cycle aspects. The better they understand the activities that systems engineers perform, the better customers know what to request, how to request it, how much to pay for it, and how to judge the quality and value of the results of systems engineering. In short, what customers need to grasp is how systems engineers participate in the realization of engineered systems resulting in products, services, enterprises, and systems of systems (SoS).

The SEBoK assists the customers of systems engineering by providing a broad, comprehensive treatment of the concepts, principles, theory, and practice related to systems in general and SE in particular. Its references inform customers about books and articles that provide important perspectives on systems and SE.

Customers of SE include:

- sponsors of internal SE organizations
- organizations that maintain long-term customer-domain relationships with external SE organizations, and
- organizations that outsource SE functions to general-purpose SE organizations.

The two vignettes below show how the SEBoK can assist SE customers. In one, the customer of an internal, corporate SE organization leads the transition to a mobile supply chain management system. In the other, the customer of a mixture of customer-domain and other SE organizations presides over the SE of a catastrophe-response sSoS, which entails integration over multiple domains.

Use of Topics

For customers of SE, most parts of the SEBoK offer immediately relevant knowledge about SE.

Part 1:

- explains the relationship between SE, system development, and project management,
- summarizes overall trends in the rate of growth of systems interdependency, complexity, assurance levels, and pace of change, and of the evolving nature of integrated hardware-software-human systems, and
- provides pointers to other parts of the SEBoK of interest to customers.

Part 3:

- explains evolving system life cycle models and their elements, indicating which elements are SE-intensive (see Life Cycle Models),
- provides overall perspectives on customer participation in SE activity,
- identifies customer influence points on SE activity, and
- explains how customers can express their concerns in the form of needs, expectations, and requirements (see System Definition).

Part 4:

- explains how the SE function varies by class of system product, service, enterprise, and systems of systems engineering).

Part 6:

- explains how SE relates to project management, procurement and acquisition, and specialty engineering for such customer-intensive specialties as safety, security, maintainability, usability, and affordability.

Part 7:

- provides case studies and vignettes to illustrate how the parts have been used in similar situations, presenting successes to emulate and failures to avoid.

If there is a central theme here, it is that the quality of customer input is critical. That is because the systems engineer evaluates customer input, then uses it in formulating an approach to defining and realizing the system. Part 3 addresses this, explaining that the customer should expect the systems engineer to provide:

- a well-architected product, service, enterprise, or system of systems that meets customer needs and expectations (again, this depends on high quality input from stakeholders — see System Definition)
- a managed life cycle model from the customer need and requirements to the delivered product, service, enterprise or system of systems (see Life Cycle Models)
- verification that the system-of-interest (SoI) meets the needs and requirements of the stakeholders, and
- validation that the final result, when deployed in an operational environment, provides the value added that was desired are critical to systems engineering (see System Realization and System Deployment and Use).

Implementation Examples

Good examples provide a basis for deeper understanding. In Part 7, the SEBoK provides summaries of and references to full case studies, as well as overviews of events (vignettes). These are linked back to the appropriate areas of the SEBoK and a matrix is provided that shows the primary areas of the SEBoK addressed by each case study or vignette. Readers can use the matrix to find case studies and vignettes - and through these, references - that relate to their concerns.

Vignette: Mobile Supply Chain Management

Barbara Bradley is the Director of Supply Chain Management Systems for a large manufacturing company. Her main area of expertise is transportation logistics. She has led the evolution of a highly successful corporate supply chain management system based on desktop and mainframe technology, more by making incremental strategic choices than by applying formal SE.

Now, many of her suppliers and distributors adopt mobile devices and cloud services and Barbara sees that her own company must do the same. The company's status quo approach of incremental, ad hoc choices is clearly inadequate for a technology transition of this magnitude. Not only that, but the company must evolve to the new mode of operation while providing continuity of service to the supply chain stakeholders.

Barbara decides that these challenges require formal SE. As a first step, she plans to put together a Next-Generation Supply Chain Management System integrated product team (IPT). Members of the IPT will include Barbara's supply chain experts, her supply-chain success-critical stakeholders, and the corporate SE organization.

Barbara has never used the corporate SE organization before, and wants to better understand an SE organization’s overall capabilities and modes of operation. She turns to the SEBoK for answers to the questions about SE that are on her mind:

- How do we maintain continuity of service while pursuing incremental development?
  - What choices about life cycle models can make this possible?
- What is the role of the customer in defining systems of interest (SoIs)?
  - How do we provide guidance to the customer in expressing needs, concerns, and requirements?
- What is the role of the customer at early decision milestones?
  - How do we ensure that results of our interaction with the customer include well-architected products and thorough development plans, budgets, and schedules?
- What is the role of the customer in product acceptance, specifically when we verify stakeholder requirements and when we validate the final result?

Barbara seeks the answer to one question in Part 4: Applications of Systems Engineering:

- Given that a supply chain management system combines product, service, enterprise, and SoS views, how do we understand what goes into all those views, and keep the overall picture clear?

Barbara's final question is addressed in Part 6: Systems Engineering and Other Disciplines:

- How do we integrate SE and software engineering (SwE)?

Once in command of the answers to these questions, Barbara is ready to lead the IPT in analyzing, negotiating, and defining an approach that is satisfactory to all of the success-critical stakeholders. By having the IPT members read the portions of the SEBoK that she has found most valuable, Barbara begins to build a shared vision within the IPT. As the IPT defines a Next-Generation Supply Chain Management System and prepares the transition from the old system to the new, the SEBoK is an important tool and resource.

Vignette: Catastrophe-Response System of Systems

Ahmed Malik is the Information Systems Division General Manager in his country's Department of Natural Resources. The country suffers frequent wildfires that destroy crops, forests, villages, and parts of cities, and also cause problems with emergency care, crime prevention, and the water supply.

During a recent catastrophic wildfire, personnel responsible for firefighting, crime prevention, traffic control, water supply maintenance, emergency care facilities, and other key capabilities found themselves unable to communicate with each other. As a result, the Minister for Natural Resources has been tasked with improving the country's catastrophe response capabilities, and has named Ahmed as the SE customer lead for this effort.

The Minister suggests that Ahmed organize a workshop to scope the problem and explore candidate solutions to the communications problems. Ahmed invites the various actors involved in catastrophe response — medical, insurance, and news media organizations from both public and private sectors. He also invites SE organizations with SoS experience.

Ahmed has strong experience in information SE, but none in the development of SoSs. To come up to speed in his role as the SE customer lead, Ahmed turns to the SEBoK Part 3: Systems Engineering and Management. To better understand the challenges of SoS SE, he studies the SoS knowledge area in Part 4, and its references. Ahmed also schedules meetings with the leading SoS SE provider organizations, who are eager to tell him about their capabilities. Overall, Ahmed looks for both guidance and pointers to candidate solution sources in the SEBoK.

Thus prepared, Ahmed structures the workshop to address three key challenges:

- mutual understanding of organization roles, responsibilities, and authority
- summary analyses of previous catastrophe response communication gaps and needs
- candidate solution capabilities in communications, data access, geolocation services, public emergency warning systems, coordinating evacuation procedures, architectural connector approaches for improving interoperability, and sharable models for evaluating alternative solution approaches.

The workshop brings the primary organizations involved in catastrophe responses together with the most capable SoS SE provider organizations. The results of their discussions provide Ahmed and his Minister with sufficient information to prepare a phased plan, budget, and schedule for incremental development of improved catastrophe response capabilities, beginning with simple interoperability aids and analysis of architecture alternatives for performance, scalability, and feasibility of evolution from the initial simple fixes. The plan is then iterated with the key stakeholders, and converged to a common-consensus approach for achieving strong, credible early improvements and a way forward to a much more scalable and cost-effective catastrophe-response SoS.

This vignette is based on the Regional Area Crisis Response SoS (RACRS) in (Lane and Bohn 2010).

Summary

For the customers of SE, the SEBoK provides both general and specific knowledge that will help users gain important insight in relating to systems engineers. Key to this is learning about life cycles, the definition of SoIs, and how to provide guidance in expressing needs, concerns, and requirements. Further, customers need to know what to expect as a result of SE activities in the form of well-architected products, services, enterprises, or systems of systems and a managed life cycle. The results of verification of stakeholder requirements and the validation of the final result in respect to fulfilling the user needs are vital.

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< Previous Article | Parent Article | Next Article >

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Use Case 4: Educators and Researchers

For educators or researchers, the SEBoK should be used together with GRCSE (*Graduate Reference Curriculum for System Engineering*). The SEBoK is a guide to the knowledge that constitutes the system engineering domain, while GRCSE [1] "describes a program for a professional master's degree focused on developing student ability to perform systems engineering tasks and roles" (Pyster et al. 2012).

An educator, for purposes of this use case, is a university faculty member or a professional trainer. Educators use the SEBoK and the GRCSE to develop curricula or courses focused on systems engineering (SE) generally, on domain-centric systems engineering, or on another engineering discipline that touches on SE. The SEBoK and GRCSE are means to assure accuracy, completeness, and effective assessment at all levels, from lessons through objectives.

A researcher, for purposes of this use case, is a person actively contributing to the body of SE knowledge.

The Use of Topics

Educators can use SEBOK topics and their primary and additional references as:

- assigned readings for courses,
- supplemental references for student research, and
- content for curriculum development.

Educators can also use the concepts, perspectives, and references to develop or refine course objectives and the techniques for assessing them.

Researchers can use SEBoK topics and their primary and additional references to learn about the state of the art in the subject areas of interest, for summaries of the literature, and to look for opportunities to advance those areas by further research.

A good course or research topic should reflect multiple perspectives, which the SEBoK provides. As well, cataloging the wide diversity in accepted practices across SE is an important function of the SEBoK from the researcher's perspective.

For both educators and researchers, the fact that the SEBoK provides both primary and additional references in each topic is useful. So is the fact that the SEBoK is a wiki, which allows frequent updates to keep pace with the dynamic evolution of the systems engineering domain. See Acknowledgements and Release History.

Implementation Examples

Good examples make for good teaching. The Systems Engineering Implementation Examples in the SEBoK consist of relatively in-depth case studies and shorter vignettes, which are linked back to appropriate areas of the SEBoK. A matrix shows which SEBoK topics are addressed by each case study or vignette.

Each case study in the SEBoK is actually a summary of an original case found in the SE literature, and is accompanied by a reference to the full, published case study. Case study summaries or vignettes from the SEBoK may be incorporated in curricula.

Educator

University faculty may use the SEBoK and GRCSE to develop:

- a complete SE curriculum,
- a single course in systems engineering, either for use in an SE curriculum, or in a curriculum that belongs to some other discipline, or
- assessment criteria for curricula or courses.

Likewise, professional trainers use the SEBoK to develop training material, or to evaluate or update existing training courses.

Both faculty and trainers pursue professional development, in the form of SE study, using the SEBoK.

Vignette: Curriculum and Course Development

A university designates a faculty team to investigate the feasibility of developing a graduate degree in SE.

Results of preliminary feasibility analysis (including evaluating the market, competing degree programs, and so on) are encouraging. The faculty team then begins to design the program, by identifying:

- program constituents
- potential objectives, outcomes and entrance requirements, based on review of GRCSE
- one half of the of the curriculum content, based on review of the typical curriculum architecture (GRCSE chapter 5) and the core body of knowledge (CorBoK) (chapter 6) of GRCSE and
- the other half of the curriculum content based on review the SEBoK (Parts 2 through 7) .

According to the GRCSE, 50% of the total knowledge conveyed in a graduate program should be based on the CorBoK, to assure a common foundation among programs offered at different institutions. At the same time, restricting the CorBoK to no more than 50% encourages a healthy variety in those programs.

Once these steps are complete, the overall architecture and the content and the scope of the curriculum are defined. Now the faculty designs the courses themselves, defining in turn:

- the prerequisites for each course
- the overall course sequencing for the curriculum, based on the course prerequisites
- the objectives and goals for each course and
- the expected outcomes of each course.

Finally, the faculty is ready to develop the content for each individual course.

Defining course content is done based on topics in the SEBoK that cover the subject of the course.

Using primary and additional references as much as the topics themselves, the faculty responsible for course design define:

- the scope of the course content
- the course coverage, that is, what within the course content scope is actually taught in the course.

Given the scope and coverage, the next and final step is to develop the course material.

A professional trainer designing the training material performs the same kinds of activities. To customize the training course for a specific industry or customers, the trainer may integrate domain-specific content as well.

Researcher

Researchers use SEBoK topics and their primary and additional references to learn about the state of the art in the subject areas of topics, and to look for opportunities to advance those areas by further research.

Vignette: Software Engineering Research

William McGregor, a software engineer, wants to learn more about software intensive systems (SIS). Initially, William wants to answer the question: Do the activities and practices used to develop SIS represent special treatments of standard activities and practices?

William has already reviewed the SWEBoK and its primary references extensively for an answer to his question. In the course of his research, William learns about the SEBoK and decides to look there, too.

William finds no specific discussion of the SIS within the SEBoK. As he looks through the SEBoK, though, he realizes that there are activities throughout the system development life cycle which can be adapted or customized for the development of SIS. Accordingly, William decides to replace his original question with two new ones: (a) what best practices are applied throughout the software development life cycle and (b) how can those practices be adapted to SISs?

William now focuses on Part 3 to learn about the system development life cycle, and identify development activities and practices that he can customize for software intensive systems.

Summary

Educators use the SEBoK as a framework or a resource which helps them:

- determine what subject matter should be included in a new curriculum
- identify gaps in an existing curriculum and craft plans to address those gaps, and
- design individual courses.

The case studies and vignettes in the SEBoK may be used by educators in the classroom.

To develop curricula at the program level, educators should use the SEBoK in tandem with the GRCSE.

Researchers use the SEBoK to learn about the state of the systems engineering discipline, and to look for opportunities to advance that state by further research.

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Additional References

None.

< Previous Article | Parent Article | Next Article >

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References

[1] http://www.grcse.org

Use Case 5: General Managers

General managers preside over system development projects, system acquisitions, product lines, systems of systems (SoSs), and commercial and government organizations. For general managers, the SEBoK serves as a primary information source and quick, comprehensive reference for systems engineering information.

In particular, the SEBoK helps the general manager understand:

- the boundaries and synergies among systems engineering (SE), systems development, project management (PM), and life cycle support
- how those boundaries and synergies are likely to evolve with increasing use of evolutionary development, lean and agile methods, and systems that provide purchased services as opposed to salable products
- how to best balance a mix of hardware, software, human factors, domain, and specialty-area systems engineers and
- how an organization can evolve to take advantage of the trend towards cross-discipline systems engineers.

Use of Topics

For general managers, most parts of the SEBoK offer immediately relevant knowledge about SE.

Part 1:

- explains the relationship between SE, system development, and project management
- summarizes overall trends in the nature of systems interdependency, complexity, assurance levels, and pace of change
- describes the evolving nature of integrated hardware-software-human systems and
- provides pointers to other parts of the SEBoK of interest to general managers.

Part 3:

- explains evolving system life cycle models and their elements, indicating which elements are SE-intensive (see Life Cycle Models) and
- provides overall guidance on the management of SE activity.

Part 4:

- explains how the SE function varies by class of system product, service, enterprise, and systems of systems engineering).

Part 5:

- explains SE governance and competence development.

Part 6:

- explains how SE relates to software engineering, project management, industrial engineering, procurement and acquisition, and specialty engineering for such specialties as safety, security, maintainability, and usability.

Part 7:

- provides case studies and vignettes to illustrate how the parts have been used in similar situations in successes to emulate and failures to avoid.

Vignette: Emerging Nation Satellite System

Tom Lee is General Manager for Telecommunications in a ministry of a large emerging nation. The government does not have much existing capability for developing capital-intensive infrastructure projects. The government decides to use a major investment in technology as a vehicle to develop national enterprise capabilities.

To accomplish this, the minister assigns Tom to lead a project to develop a national satellite system for telecommunications and earth resources observation. Tom understands that this is a very complex system, and decides to do some background research. During this research, Tom discovers the SEBoK and decides that is may be a useful resource.

Tom first reads:

- Part 1 for an overview and pointers to relevant sections of Parts 3 through 6,
- portions of Part 3, Part 4, Part 5, and Part 6 to learn about the life cycle, nature, scope, and management aspects of enterprise SE,
- the successful satellite system case studies in Part 7 (Global Positioning System, Miniature Seeker Technology Integration spacecraft) for approaches to emulate, and
- the satellite system case study in Part 7 which describes development and integration problems (Hubble Space Telescope) for pitfalls to avoid.

Tom continues by carefully reading Part 5. He realizes that he must develop simultaneously individuals, teams, and the enterprise. The knowledge areas (KAs) from Part 5 give useful background. For this project, Tom enlists both a proven multi-national satellite SE company and some of his brightest aerospace systems engineers. Tom expects his local systems engineers to learn from the SE company, and he plans to use them as the core group of the national satellite system as it ultimately develops and operates.

He realizes that correct problem definition and requirements setting will be critical first steps. He carefully reads the Concept Definition and System Definition KAs. As his team develops the Stakeholder Needs and Requirements and the System Requirements, he makes sure they follow good practices as listed in the SEBoK. Once architectural designs have been proposed and approved, he requires his team to perform cost-benefit tradeoff analyses of alternative solutions.

Thus prepared, Tom is confident that he can formulate and execute a successful approach.

Vignette: Commercial Safety Equipment Company

Maria Moreno is General Manager at Safety First Equipment Company, specialists in hardware-intensive safety equipment. Maria's background is in electromechanical systems. Safety First is highly successful, but beginning to lose market share to competitors who offer software-intensive capabilities and user amenities.

Maria is preparing an initiative to make Safety First into a leading software-intensive safety equipment provider. She decides to make the SEBoK a primary resource for gathering concepts and insights for the initiative. She begins by skimming through all of Parts 1 through 6, both to become familiar with the SEBoK itself and to start organizing her thoughts on SE.

Now Maria is ready to focus on subjects of prime importance to her task. Here are those subjects, listed with the places in the SEBoK where she find information about them.

In Systems Engineering and Software Engineering in Part 6:

- the nature of software
- differences between hardware and software architectures and practices and
- key aspects of managing software teams.

In the article Human Systems Integration in the Systems Engineering and Specialty Engineering knowledge area, also in Part 6:

- the SE of user amenities.

In the Next Generation Medical Infusion Pump Case Study in Part 7:

- the software aspects of safety practices, such as software fault tree analysis and failure modes and effects analysis and
- overall approaches for concurrent engineering of the hardware, software, and human factors aspects of safety-critical equipment.

In the Medical Radiation Case Study in Part 7:

- hardware-software pitfalls to avoid in safety-critical equipment.

Maria chose the last two items from among the case studies in Part 7 because being safety-critical, they contain lessons directly applicable to her initiative at Safety First.

With this framework of concepts and practical information in place, Maria begins assembling a core team of Safety First systems engineers, complemented by external experts in software and human factors engineering. Maria wants the team to begin by developing a shared vision. To that end, she asks them to read the portions of the SEBoK that she has found most valuable in assessing the challenges of transitioning Safety First into a leading software-intensive, user-friendly safety equipment provider.

Summary

For the general manager whose organization includes systems engineers, the relationship between SE, systems development, project management, and life cycle support is a central concern. The SEBoK provides insights and guidance about this and other aspects of SE principle and practice, and explains the role of SE in a variety of management challenge areas and application domains.

The SEBoK complements the general management guidance available in sources such as the *PMBOK® Guide* (PMI 2013).

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< Previous Article | Parent Article | Next Article(Part 2) >

SEBoK v. 1.4 released 29 June 2015

SEBoK Discussion

Please provide your comments and feedback on the SEBoK below. You will need to log in to DISQUS using an existing account (e.g. Yahoo, Google, Facebook, Twitter, etc.) or create a DISQUS account. Simply type your comment in the text field below and DISQUS will guide you through the login or registration steps. Feedback will be archived and used for future updates to the SEBoK. *If you provided a comment that is no longer listed, that comment has been adjudicated. You can view adjudication for comments submitted prior to SEBoK v. 1.0 at SEBoK Review and Adjudication. Later comments are addressed and changes are summarized in the Letter from the Editor and Acknowledgements and Release History.*

If you would like to provide edits on this article, recommend new content, or make comments on the SEBoK as a whole, please see the SEBoK Sandbox [3].

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