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Systems Engineering and Industrial Engineering

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Abstract Systems engineering overlaps with many fields, such as industrial engineering, engineering management, operations research, project management, and design engineering. In fact, the main industrial engineering body of knowledge, the Industrial and Systems Engineering Body of Knowledge, includes systems in the title and includes a section on systems design and engineering, which references the Systems Engineering Body of Knowledge. This paper describes the similarities and differences between systems engineering and industrial engineering based upon the respective standards, handbooks, and bodies of knowledge. Based on this assessment, we describe potential roles systems engineers and industrial engineers perform during a system's life cycle. We conclude with a summary of our paper.

Introduction

When systems engineers and industrial engineers are in the same organization, they have different roles and responsibilities. While job titles vary by organization, many organizations have individuals that perform both systems engineering (SE) and industrial engineering (IE) activities. The goal of this paper is to help systems engineers and industrial engineers better understand their different perspectives of the fields and the knowledge needed to meet the needs of their organizations and customers. To achieve this goal, we compare the use of international standards and the contents of the bodies of knowledge in systems engineering and industrial engineering by using published information provided by the major professional society of each field.

We organize the rest of the as follows. First, we briefly identify the standard for systems engineering and summarize the SE Body of Knowledge (SEBoK) (INCOSE, 2021). Second, we identify the use of standards in IE and briefly describe the industrial engineering body of knowledge (ISEBoK). Third, we use a Venn diagram to compare the two bodies of knowledge. Finally, we conclude with some findings and recommendations.

Systems Engineering

The International Council on Systems Engineering (INCOSE) is a "not-for-profit membership organization founded to develop and disseminate the interdisciplinary principles and practices that enable the realization of successful systems." INCOSE defines systems engineering as

> *a transdisciplinary and integrative approach to enable the successful realization, use, and retirement of engineered systems, using systems principles and concepts, and scientific, technological, and management methods.* (INCOSE, 2021)

We use the terms "engineering" and "engineered" in their widest sense: "the action of working artfully to bring something about." "Engineered systems" may be composed of any or all of people, products, services, information, processes, and natural elements.

INCOSE aligns their SE Handbook and the SeBoK with the ISO/IEC/IEEE 15288, System Life Cycle Processes, which focuses on processes. SE is process orientated. Each edition of the Systems Engineering Handbook aligns to an ISO/IEC/IEEE 15288 edition. Figure 1 shows the overall structure of the eight parts of the SEBoK. (SEBoK, 2021) This connection to a standard ensures that practitioners use consistent language and processes that align with best practices. This helps them accomplish their goals and achieve greater value.

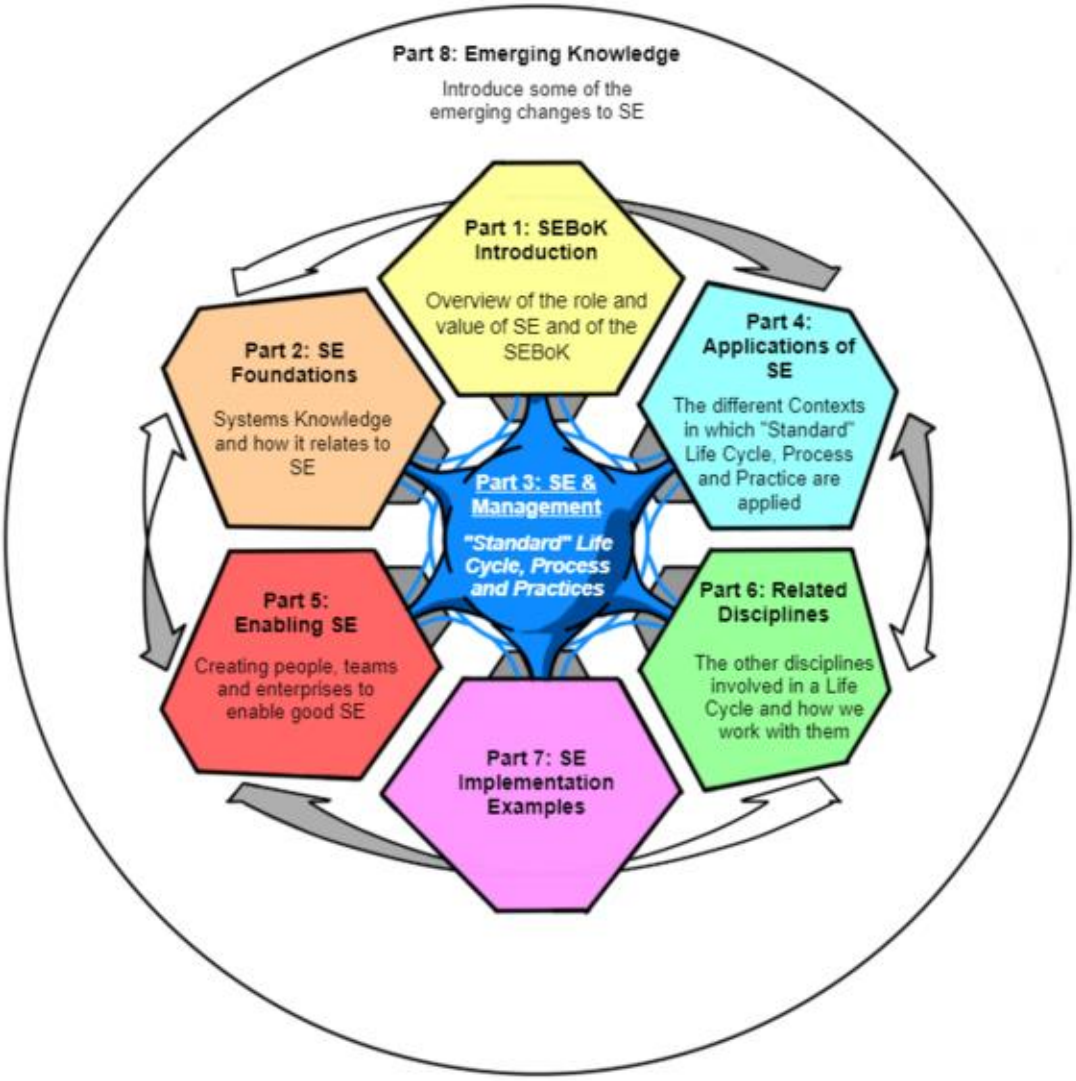

Figure 1. Structure of the SEBoK. (SEBoK, 2021)

The major SE and Management processes and activities are in Part 3 of the SEBoK as shown by its central role in Figure 1. Figure 2 shows the 15288 processes and how they align with the SE Handbook and SEBoK topic areas. We will use these SEBoK topics of knowledge areas to compare with the knowledge areas of IE in a subsequent section of the paper. The knowledge areas in Figure 2 align with the system life cycle if we start at the top left of the first column and traverse to the bottom, continue at the bottom of the second column and traverse to the top, and continue at the bottom of the third column and traverse to the top.

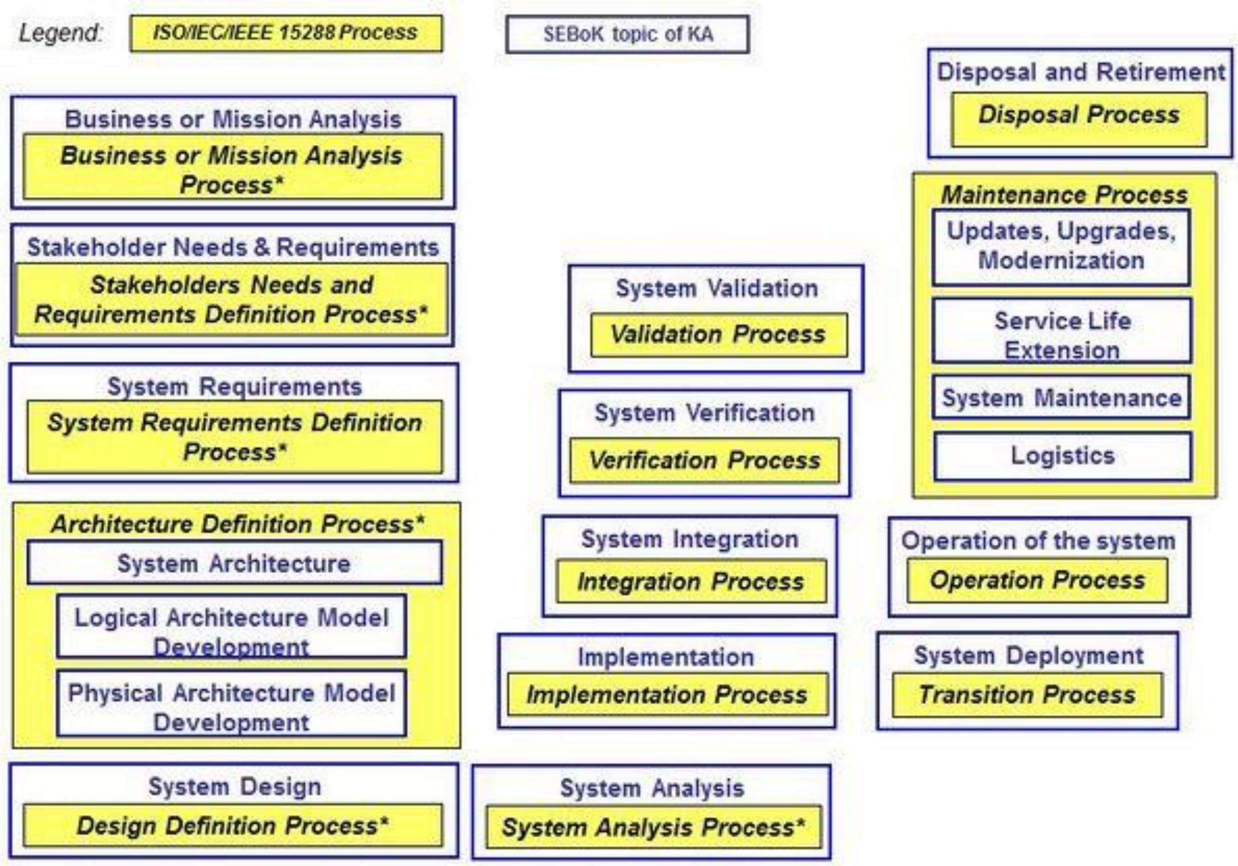

Figure 2. Mapping of Technical Topics of Knowledge Areas of SEBoK with ISO/IEC/IEEE 15288 Technical Processes. (SEBoK, 2021)

Industrial Engineering

The Institute of Industrial and Systems Engineers (IISE) states that it is "the only international, non-profit, professional society dedicated to advancing the technical and managerial excellence of industrial engineers." (IISE, Origins of IISE, 2021). IISE started in 1948 as the American Institute of Industrial Engineers. In 1981, the organization was renamed the Institute of Industrial Engineers to reflect its growing international membership. In 2016, the membership voted to change the name to the Institute of Industrial and Systems Engineers. This addition reflects a vote by its membership and aligns with the "changing scope of the profession that, while keeping its industrial base, has seen more industrial and systems engineers working with large scale integrated systems in a variety of sectors".

IISE developed the ISE Body of Knowledge in 2021 (IISE, 2021). The ISEBoK has 14 knowledge areas, as shown in Figure 3. The first 13 knowledge areas identify the industrial engineering knowledge, and the fourteenth is Systems Design and Engineering, which references the SEBoK. The current ISEBoK provides a short description of each the knowledge area, a detailed outline of knowledge area topics, and a list of references. The ISEBoK does not use standards as its foundation. In fact, the Standard Practice for Systems Safety (MIL-STD-0-882D) is the only standard cited in the reference section. IISE does not currently have a handbook developed by or for the institute. Although McGraw-Hill will release the 6th edition of *Maynard's Industrial and Systems Engineering Handbook* in 2022. The new edition aligns with the ISEBoK.

Figure 3. Industrial and Systems Engineering Knowledge Areas

The 14 topic areas included in the ISEBoK connect to international standards even though it does not use standards as its foundation or provide references for standards in most of the topic areas. We used key words developed from each topic area's name to search the International Organization for Standardization (ISO) website (ISO, 2021) to find a rough estimate on the number of standards in each topic area. This search found 100s of potential standards. We do acknowledge that a standard that mentions one of the key words may or may not be relevant. Examples of areas that did not yield any ISO standards from the search are operations research/analysis and engineering economic analysis. This does not mean that those areas do not have applicable standards. Organizations other than ISO do produce guidelines or principles to help practitioners. For example, the environmental protection agency provides guidelines on economic analyses (EPA, 2021). The quality and reliability engineering area used to rely heavily on Mil-Std's, many of which were eliminated with acquisition reform in the Department of Defense. The addition of referencing standards could help IE practitioners by providing additional information on best practices in each knowledge area. This would help ensure practitioners are using the right techniques, processes, knowledge, etc. appropriately.

Venn Diagram Comparison

We realize that organizations use different job titles, and the same job title may have different responsibilities in different organizations. In this section, we compare the two bodies of knowledge. We present a Venn Diagram to identify the knowledge areas that are usually performed by systems engineers (SE), the ones usually performed by industrial engineers (IE), and the knowledge area descriptions that are used by both disciplines. Figure 4 provides the diagram. The numbered topics are the knowledge areas explicitly identified in the ISEBoK.

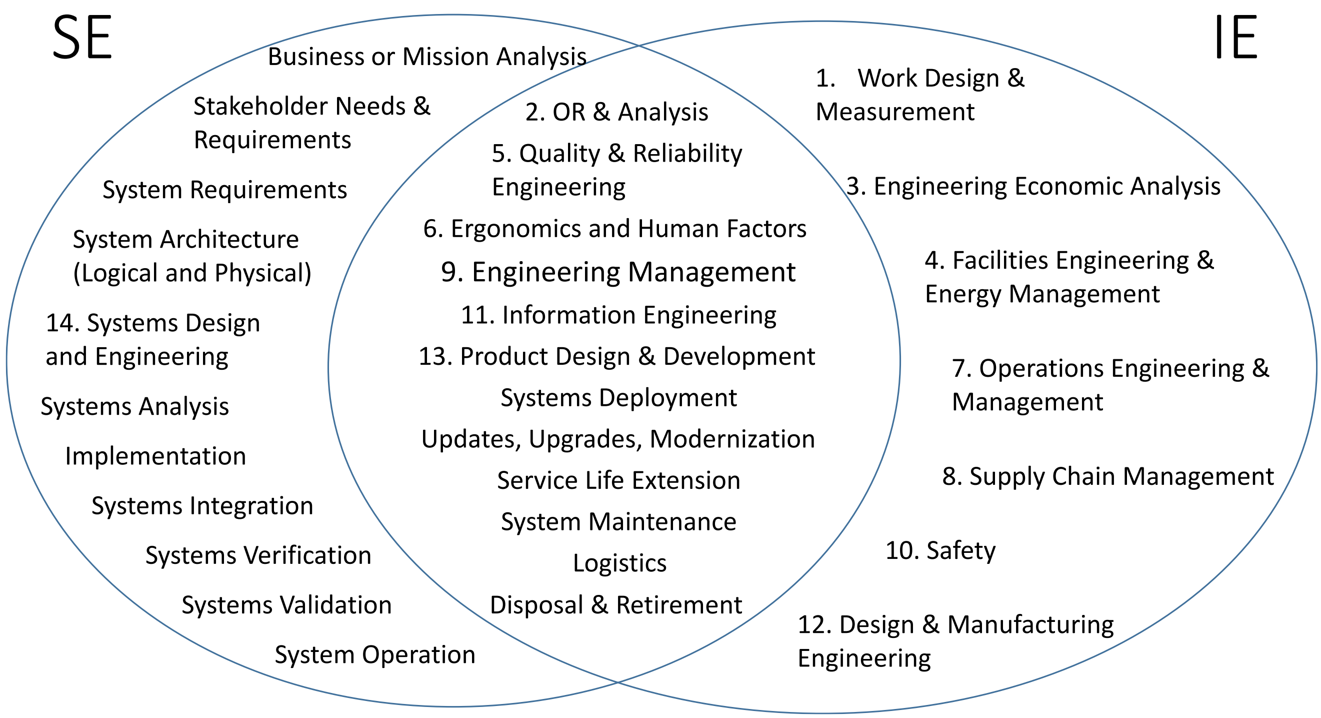

Figure 4. Venn Diagram

We identified 11 primarily SE knowledge areas, 7 IE primarily knowledge areas, and 12 overlapping knowledge areas. Table 1 provides some illustrative examples of the differences in SE and IE focus of the overlapping knowledge areas, seen in Figure 4.

Knowledge Area	SE Focus	IE Focus
2. Operations Research (OR) and Analysis	OR and analysis is used in systems analysis to assess system performance and to evaluate system designs (Levis & Wagenhals, 2000; Wagenhals, Shin, Kim, & Levis, 2000; Wagenhals, Haider, & Levis, 2003; Raz, Kenley, & DeLaurentis, 2018)	OR and analysis is used to optimize operations, maintenance, and logistics. OR is also used to evaluate and optimize manufacturing systems.

5. Quality & Reliability Engineering	Quality and reliability requirements are treated as system-wide performance requirements (Buede &Miller, 2016, 157-159; Wymore 1993, 401) that are assessed at the systems level. One example is availability, A_0, which measures the degree to which a system is either operating or can operate at any time when used in its typical operational and support environment. (DA PAM 70-3 2008, 87)	Quality and reliability are used to evaluate and improve the manufacturing process of goods and services. Reliability is also used to evaluate and improve system operations.
6. Ergonomics and Human Factors	Ergonomics and human factors are considerations in assessing the potential usability of a system for end-users in an operational environment. According to Buede and Miller (2016, 180), "Performance elements of usability are ease of learning (learnability), ease of use (efficiency), ease of remembering (memorability), error rate, and subjectively pleasing (satisfaction)."	Ergonomics and human factors are used to assess and improve manufacturing and operational processes. They are also used to assess and improve the actual usability of products and services.
9. Engineering Management	Engineering managers and SEs work with program managers to develop and improve new products and services.	Engineering managers and IEs support operations managers responsible for manufacturing processes and the operation of systems providing products and services.
11. Information Engineering	Information Engineering is critical to the development of new products and services that are increasingly software intensive. Information engineering is relevant for model-based systems engineering software tools and databases, requirements management software tools and databases, and overall configuration management of the systems design and requirements baseline.	The Information Engineering knowledge area focuses on using data in information systems to facilitate decision-making and business communication.
13. Product Design & Development	SE focuses on the design of systems that provide products and services and the system life cycle. SE includes the technical processes for system design and verification and the technical management processes for project planning, assessment, and control; risk management; and decision management in the *Systems Engineering Handbook* (2015, 47-83, 104-121).	The knowledge area of the ISEBoK (2021, 53-46) focuses on the design of products and the product life cycle. It closely parallels the technical processes for system design and development of SEBoK.

Systems Deployment	SEs participate in defining requirements, defining the architecture, and verification and validation of deployment systems needed to the deploy the system of interest, e.g., special transport equipment such as the Shuttle Carrier Aircraft (SCA) that NASA used to transport Space Shuttle orbiters. (Jenkins 2000)	IEs are more focused on air, ground, water, and intermodal logistics to include transportation and distribution of systems and products.
Updates, Upgrades, Modernization	SEs are involved defining requirements, defining the architecture, and verification and validation of updates, upgrades, and modernization of systems. One way that this has been explained is that a second iteration of the systems engineering V-model is completed as the systems remains in service while a system change project is implemented (Ven, Talik, and Hulse 2012).	IE's are involved in manufacturing processes and supporting operations of systems to provide goods and services. IEs can help identify the need for updates, upgrades, and modernization of manufacturing and service processes and work with EMs, SEs, and design engineers to provide improved capabilities.
Service Life Extension	SEs are involved in service life extension efforts in the same way that they are involved in updates, upgrades, and modernization of systems.	IEs are involved in service life extension efforts in the same way that they are involved in updates, upgrades, and modernization of systems.
System Maintenance	SEs participate in defining requirements for maintenance across the life cycle of the system, determine the impact of maintenance constraints on the system requirements and the system architecture (Walden et al, 2015, 97-98).	IEs provide engineering support to production processes maintenance and system maintenance to sustain operation of production and service processes and systems.
Logistics	SEs participate in defining requirements for logistics across the life cycle of the system, determine the impact of maintenance constraints on the system requirements and the system architecture (Walden et al, 2015, 97-98).	IEs are very involved in logistics planning and operations including supply chain management, transportation, and distribution.
Disposal & Retirement	SEs identify requirements, define the architecture, and verification and validation of disposal and retirement needed to the disposition or retire the system of interest, e.g., nuclear material stabilization processes and equipment needed to disposition fissile nuclear materials to enable shutdown of the nuclear production facilities (Kenley, et al, 1999).	IEs plan for disposal and retirement as part of their product design process. Increasingly, IEs must consider environmental impact and sustainability issues.

Table 1. Illustrative Examples of SE and IE Overlapping Knowledge Area Differences

Roles in a System Life Cycle

Systems Engineers and Industrial Engineers have important roles in a system life cycle. Figure 5 modifies a format used in the literature (Buede & Miller, 2016). We have identified the system life cycle stages and, based on our analysis in the previous section, identified and summarized the major roles of SEs, IEs, and Design Engineers (DE). DEs can be SEs, IEs, or other disciplines and used here signify the actual designer of a system. We have aggregated some of the processes to simply the chart.

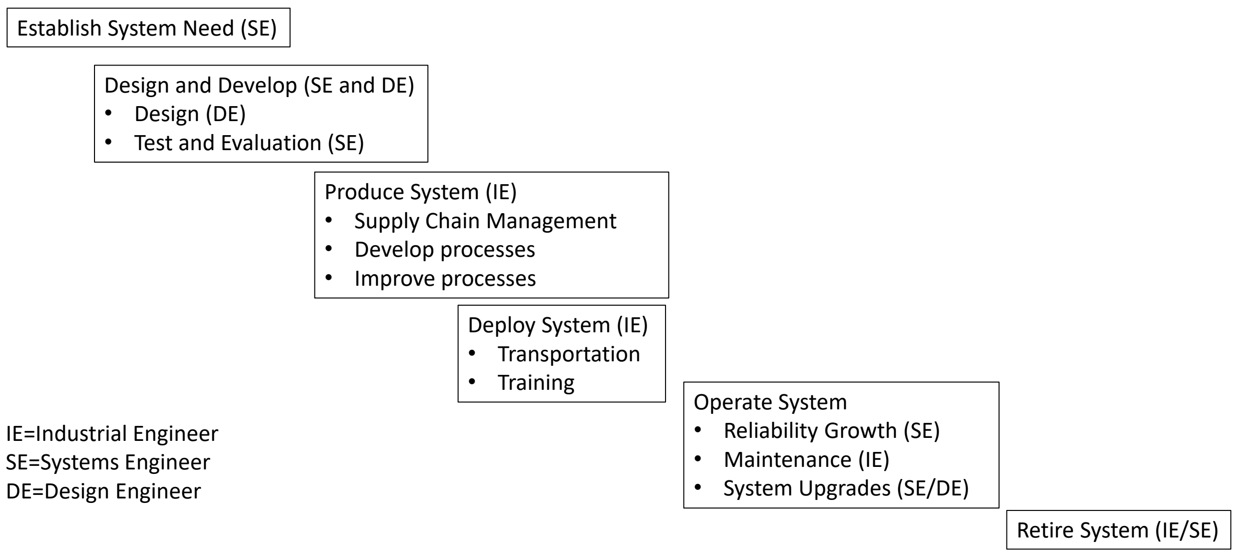

Figure 5. Roles in a System Life Cycle

Figure 5 aligns with Figure 4. In general, SE and IE both contribute to product or service design, implementation, and retirement in various ways through the system life cycle. Both use various information, analyses, and techniques in these stages. This is seen in the overlapping topic area of Figure 4. The distinguishing differences are seen by looking at Figure 4 and 5 holistically. In general, SEs focus on working with various stakeholders to enable, validate, and verify the value created by the product or service. Therefore, SEs help establish the system need and contribute to the design, development, test & evaluation, operation, and retirement of the system. This includes working with various engineering teams to manage and aggregate design and information in a holistic manner. IEs non-overlapping knowledge areas focus on production, deployment, operations, and retirement. For many IEs, their major focus is production, transportation, and maintenance processes.

Summary

The purpose of this paper was to compare the knowledge areas of SE and IE. We used the SEBok and the ISEBoK for this comparison. Based on our analysis we conclude the following.

- SE and Management knowledge areas are based on an ISO standard. IE has several related ISO standards. IISE does not link their BoK to standards.

- Based on the respective bodies of knowledge, SE is more process focused, while IE focuses more on concepts and techniques. SE and IE have overlapping bodies of knowledge.

- The SEBoK and the SE Handbook align with the system life cycle. The ISEBoK does not have an apparent organizing structure.

- SEs and IEs have important roles in the system life cycle.

There are many ways to determine the skills required for a particular field. This paper uses the body of knowledges from the two major professional societies (INCOSE and IISE) to compare the knowledge areas of SE and IE. Another method and possible future study would be to use natural language processing to review job postings from both fields. Additionally, a future study could be to survey academic programs in both fields.

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Biography

Dr. Gregory Parnell is a Research Professor in the Department of Industrial Engineering at the University of Arkansas and Director of the M.S. in Operations Management program. He was lead editor of *Decision Making for Systems Engineering and Management*, (2nd Ed, 2011), lead author of the *Handbook of Decision Analysis, Wiley Operations Research/ Management Science Series* (2013), and editor of *Trade-off Analytics: Creating and Exploring the System Tradespace*, (2017). He previously taught at the West Point, the U.S. Air Force Academy, the Virginia Commonwealth University, and the Air Force Institute of Technology. He has a Ph.D. from Stanford University.

Dr. C. Robert Kenley is a Professor of Engineering Practice in Purdue's School of Industrial Engineering, where has been developing courses and curricula to support the educational objectives of the Purdue Systems Collaboratory. He has over 30 years' experience in industry, academia, and government as a practitioner, consultant, and researcher in systems engineering. He has published papers on systems requirements, technology readiness assessment and forecasting, Bayes nets, applied meteorology, the impacts of nuclear power plants on employment, and model-based systems engineering, and agent-based modeling for systems of systems. He is an expert system engineering professional (ESEP), and a Fellow of INCOSE.

Dr. Eric Specking serves as the Assistant Dean for Enrollment Management and Retention for the College of Engineering at the University of Arkansas. Specking received a B.S. in Computer Engineering, a M.S. in Industrial Engineering, and a Ph.D. in Engineering from the University of Arkansas. His research interest includes decision quality, resilient design, set-based design, engineering and project management, and engineering education. He is an active member of the American Society for Engineering Education (ASEE), International Council on Systems Engineering (INCOSE), and Institute for Operations Research and the Management Sciences (INFORMS) where he has served in various leadership positions.

Dr. Edward A. Pohl is Head of the Industrial Engineering Department, Professor and holder of the 21st Century Professorship of Engineering at the University of Arkansas. Dr. Pohl also serves as the Director of the Center for Innovation in Healthcare Logistics and former Co-Director of the emerging Institute for Advanced Data Analytics. Dr. Pohl is a Fellow of the Institute of Industrial and Systems Engineers, a Fellow of the Society of Reliability Engineers, a Diplomat in the Society for Health Systems and a Senior Member of the Institute of Electrical and Electronics Engineers and a member of INCOSE.