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Systems Engineering: Its Emerging Academic and Professional Attributes

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Abstract

From its modest beginnings more than a half-century ago, Systems Engineering is now gaining international recognition as an effective technologically based interdisciplinary process for bringing human-made systems into being, and for improving systems already in being. Certain desirable academic and professional attributes are coming into clear view. Others require further study, development, testing, and implementation.

This paper summarizes the heritage from which Systems Engineering entered the 21st century. Several emerging attributes of Systems Engineering education and professional practice are addressed. These include the necessary but not sufficient academic and professional activities of technical societies, degree programs and program accreditation, certification and licensing, knowledge generation and publications, recognition and honors, and considerations regarding maturity. Special attention is directed to those attributes that should be developed further to enable Systems Engineering to serve society well in this century.

I. Systems Engineering Defined and Described [1]

To this day, there is no commonly accepted definition of Systems Engineering (SE) in the literature. Almost a half-century ago, Hendrick W. Bode, writing on "The Systems Approach" in *Applied Science-Technological Progress*, said that "It seems natural to begin the discussion with an immediate formal definition of Systems Engineering. However, Systems Engineering is an amorphous, slippery subject that does not lend itself to such formal, didactic treatment. One does much better with a broader, more loose-jointed approach. Some writers have, in fact, sidestepped the issue by saying that Systems Engineering is what systems engineers do." [2]

Systems Engineering Defined. The definition of Systems Engineering and the systems approach is usually based on the background and experience of the individual or performing organization. The variations are evident from the following published definitions, with sources noted:

1. International Council on Systems Engineering: "An interdisciplinary approach and means to enable the realization of successful systems." [3]
2. Electronic Industries Alliance: "An interdisciplinary approach encompassing the entire technical effort to evolve into and verify an integrated and life-cycle balanced set of system people, product, and process solutions that satisfy customer needs. Systems Engineering encompasses (a) the technical efforts related to the development, manufacturing, verification, deployment, operations, support, disposal of, and user training for, system products and processes; (b) the definition and management of the system configuration; (c) the translation of the system definition into work breakdown structures; and (d) development of information for management decision making." [4]

3. Defense Systems Management College: "The application of scientific and engineering efforts to (a) transform an operational need into a description of system performance parameters and a system configuration through the use of an iterative process of definition, synthesis, analysis, design, test, and evaluation; (b) integrate related technical parameters and ensure compatibility of all physical, functional, and program interfaces in a manner that optimizes the total system definition and design; and (c) integrate reliability, maintainability, safety, survivability, human engineering, and other such factors into the total engineering effort to meet cost, schedule, supportability, and technical performance objectives." [5]
4. Institute of Electrical and Electronics Engineers: "An interdisciplinary collaborative approach to derive, evolve, and verify a life-cycle balanced system solution which satisfies customer expectations and meets public acceptability." [6]
5. U.S. Department of Defense: "An approach to translate operational needs and requirements into operationally suitable blocks of systems. The approach shall consist of a top-down, iterative process of requirements analysis, functional analysis and allocation, design synthesis and verification, and system analysis and control. Systems Engineering shall permeate design, manufacturing, test and evaluation, and support of the product. Systems Engineering principles shall influence the balance between performance, risk, cost, and schedule." [7]

Although the five definitions above vary, there are many common threads. Basically, Systems Engineering (SE) is good engineering with special areas of emphasis. Some of these are: a *top-down* approach; a *life-cycle* orientation; a more complete early effort regarding the *definition of system functions*, relating functions through *requirements* to design criteria, followed by an effort to ensure the *effectiveness* of early decision making within the design process on downstream outcomes; and an *interdisciplinary* or team approach applied throughout the design and development process.

Systems Engineering Described. Systems Engineering may be described as a technologically based interdisciplinary process for bringing human-made systems and their products (technical entities) into being. While the main focus is nominally on the entities themselves, Systems Engineering offers an improved strategy. Systems Engineering is inherently oriented toward "thinking about the end before the beginning" and concentrates on *what the entities are intended to do* before determining *what the entities are.*

Instead of offering systems or system elements and products per se, Systems Engineering focuses on designing, delivering, and sustaining *functionality, a capability,* or a *solution.* This strategic thinking is now being considered by forward-looking enterprises in both the private and public sectors. It is applicable to most types of technical systems, encompassing the human activity domains of communication, construction, defense, education, healthcare, manufacturing, transportation, and many others.

Systems Engineering is not a traditional engineering discipline in the same sense as civil engineering, electrical engineering, industrial engineering, mechanical engineering, producibility engineering, reliability engineering, or any of the other engineering disciplines and specialties. It should not be organized in a similar manner, nor does the implementation of Systems Engineering or its methods require extensive organizational resources. But, for best results, a well-planned and *disciplined approach* should be followed.

The Systems Engineering process involves the use of appropriate technologies and management principles in a synergetic manner. Its application requires *synthesis* and a focus on process, along with a new *thought process* to meet 21st Century challenges.[8]

II. Systems Engineering Professional Societies

In response to the growing interest in academic aspects of Systems Engineering, the American Society for Engineering Education (ASEE) established a Systems Engineering Constituent Committee (SECC) in 2002. The membership now exceeds 130, indicating considerable interest in SE by engineering educators from most of the engineering technical societies.

Among engineering technical societies, IEEE organized a Systems Council and the NDIA established a division for SE. Some engineering societies have added SE sections or divisions. The American Society for Agricultural Engineers, now the American Society of Agricultural and Biological Engineers (ASABE), has encouraged inclusion of the phrase 'biological systems' in its cognizant degree programs. Then there is the often considered change of name of the Institute of Industrial Engineers (IIE) to the Institute of Industrial and Systems Engineers (IISE).

There is one professional society that focuses exclusively on SE. It is the International Council on Systems Engineering (INCOSE, **www.incose.org**), founded in 1990 as a result of concerns about a shortage of qualified individuals prepared to think in terms of the total system. General Dynamics sponsored the first meeting in San Diego, Boeing hosted the next meeting in Seattle, and IBM facilitated an academic workshop in Northern Virginia. Among the long list of issues identified, were four that are the concern of academia:

1. Lack of clear requirements for Systems Engineering degree programs,
2. Few Systems Engineering graduates,
3. Lack of textbooks on Systems Engineering, and
4. Few accredited Systems Engineering programs.

INCOSE is an international technical council formed to develop, nurture, and enhance the multidisciplinary approach of transdisciplinary Systems Engineering as a means to enable the realization of successful systems. INCOSE has strong and enduring ties with industry, academia, and government to support two high level objectives:

1. To gain further recognition by industry, government, academia, and its sister professional societies of the importance of Systems Engineering, and
2. To achieve wide acceptance of INCOSE as a leading Systems Engineering society; and position INCOSE as a unifying force across engineering communities and specialties.

The International Council on Systems Engineering is now well established and is rapidly expanding both domestically and internationally. Enabled by more than 60 chapters worldwide and guided by a Corporate Advisory Board of 65, INCOSE is continuing to:

1. Provide a focal point for dissemination of Systems Engineering knowledge,
2. Promote collaboration in Systems Engineering education and research,

3. Assure professional standards for integrity in the practice of Systems Engineering,
4. Improve the professional status of those engaged in the practice of Systems Engineering, and
5. Encourage governmental and industrial support for research and educational programs that will improve the Systems Engineering process and its practice.

III. Systems Engineering Degree Programs

A comprehensive study of Systems Engineering degree programs in the United States was presented at INCOSE 2005, based on 2004 data.[9] That study provided a descriptive benchmark of programs encompassing academic content, administrative structure, accreditation status, and related topics. It was determined that, in 2004, there were 75 academic institutions offering 130 undergraduate and graduate degree programs in Systems Engineering.

Now, 2009 data are used in this paper for the same purpose. It is determined that 80 institutions in the US offer 165 undergraduate and graduate degree programs in Systems Engineering. This is an increase of 5 institutions and an increase of 35 SE degree programs.

To produce results comparable with the 2005 study, SE degree programs are again partitioned into two broad categories: *Systems Centric Systems Engineering Programs* and *Domain Centric Systems Engineering Programs.* The findings are summarized below from data exhibited in two tables in the Appendix. But *caution* is advised; *What's in a Name?*

Systems Centric Systems Engineering (SCSE) Programs. Basic and advanced level programs leading to a bachelors or higher degree in Systems Engineering comprise a distinct category with a discipline-like focus. Included herein are only those degree programs where the concentration is designated Systems Engineering; where SE is the intended major area of study.

There are 37 institutions that offer 56 degree programs in the SCSE category. There was no increase in the number of undergraduate programs, but graduate programs increased by 8 over the five-year study period (2004-09). The count by degree program level is given in Table 1.

Table 1. Systems Centric Systems Engineering (SCSE) Program Counts (from Appendix 1)

	BS		MS		PhD	
Program count	11	+	31	+	14	Total = 56

Domain Centric Systems Engineering (DCSE) Programs. Basic and advanced level programs leading to a bachelors or higher degrees with the major designated as X Systems Engineering, Systems and X Engineering, etc. are designated Domain Centric SE. Included in this distinct category are those degree programs naming Systems Engineering within a parent engineering domain.

A continuing desideratum is to integrate Systems Engineering topics into selected courses within the traditional engineering disciplines. Widening the number of disciplines and application areas to which SE may be applied will likely enable *systems thinking* within more engineering domains. On the basis of program names alone, there were 48 institutions with 82 DCSE degree programs in 2004. Now 52 institutions (9 of these duplicate institutions in the SCSE category) offer 109 DCSE programs across several engineering domains. These are identified in Table 2.

Table 2. Domain Centric Systems Engineering (DCSE) Program Counts (Appendix 2)

	BS	MS	PhD	
SE with Biological Engineering	18	10	6	34
SE with Computer Engineering	7	5	3	15
SE with Industrial Engineering	17	17	13	47
SE with Management Engineering	1	2	0	3
SE with Manufacturing Engineering	1	8	1	10
Totals	44	42	23	109

Organization and Administration of SE Programs. Not all Systems Engineering degree programs are administered through the classical departmental structure of the host institution. One must be aware of the administrative and organizational home for a degree program of interest to fully understand its academic context.

Most undergraduate programs are classically organized within academic departments, but at the graduate level the following variants will be found:

1. There are instances where an academic administrative unit will be the home for more than one degree program; e.g., Industrial and SE as well as Manufacturing SE. The department name may or may not subsume the names of all degree programs (e.g., Auburn U).
2. There are instances where an institution offers both SCSE and DCSE programs; e.g., Systems Engineering (SC), Biological Systems Engineering (DC), and Industrial and Systems Engineering (DC). The DCSE programs are administered within departments while the SCSE program is organized in an interdepartmental mode (e.g., VaTech).
3. In those instances where an institution offers a SCSE program at the basic and advanced levels, all are usually administered within a department (e.g., UVa). This may also be true for DCSE programs, except that the SE component may not exist at all degree levels.
4. An institution may have SE organized and administered within a center that cooperates with engineering domain departments to offer Systems Engineering (or Engineering Systems) degrees through those departments (e.g., MIT).

When considering basic and advanced level programs in the SCSE and DCSE categories, focus will be targeted properly by recognizing that Systems Engineering is broad in nature. It should not be viewed in the same context as the traditional engineering disciplines. This notwithstanding, many domains of engineering are seeking a better topical balance by adopting *systems thinking*. This is the primary reason for the rapid growth in the number of engineering academic domains adding SE topics and projects.

Over time, infusion of systems thinking into engineering curricula has been formalized in discrete courses, but Systems Engineering means different things to different people. This is especially true for the meaning imparted to degree programs by academic institutions. A degree program designated SE at one institution may not be the same as a degree program with the same designation at another. Accordingly, in considering the attributes of degree programs called Systems Engineering (whether they are SCSE or DCSE) one should go directly to the published curriculum to examine course content. At issue here is the question; *What's in a Name*?

IV. Systems Engineering Program Accreditation

The Accreditation Board for Engineering and Technology (ABET) is a federation of societies that accredits academic programs in engineering and related areas of the applied sciences. This is accomplished through four Accreditation Commissions. Unlike bodies that accredit the entire academic institution, ABET focuses on the characteristics of programs and the products of these programs for the purpose of advancing the quality thereof. [10]

The mission of ABET is accomplished through the professional engineering societies serving as participating bodies. After a seven year application and approval process, the International Council on Systems Engineering became a participating society in ABET two years ago. INCOSE has an opportunity and obligation to advance its interest in the quality of Systems Engineering education by supporting the mission of ABET.

Multiple Lead Society Concept. ABET has adopted a Multiple Lead Society (MLS) approach for accrediting degree programs that are of interest to more than one participating society. Systems Engineering is one of the first to utilize this approach, the characteristics of which are:

1. The MLS approach applies to SCSE programs, thus encouraging cooperation within SE while avoiding undue competition.
2. INCOSE assumes the nominal obligation to accredit SE degree programs (mostly SCSE) upon university request through ABET.
3. INCOSE has the opportunity to collaborate with those ABET participating societies that incorporate SE topics in their engineering domains of study (AIAA, ASME, IEEE, IIE, ISA, SAE, SME, and others that may join the MLS cluster for SE).
4. Through participating society status, INCOSE has direct involvement within academia for Systems Centric SE, and indirect influence for Domain Centric SE, all administered within the ABET programmatic accreditation enterprise.
5. At present, there are no program specific criteria for Systems Engineering. INCOSE has the opportunity to collaborate in the development of criteria for accrediting engineering programs that incorporate SE.

The ABET accreditation opportunity is viewed by INCOSE as critical to the advancement of Systems Engineering in its own right, as well as essential to the infusion of SE thinking within the domain manifestations of SE. INCOSE aspires to lead in the category of Systems Centric SE programs and collaborate with the other professional bodies participating in ABET for Domain Centric SE programs.

Accreditation of SE Programs. ABET leaves it to the institution to choose the degree level at which it will seek program accreditation; that is, to declare whether the 'first professional' degree for entry into the profession is to be at the basic or the advanced level. However, it is the policy and practice of most academic institutions to submit only undergraduate programs for ABET accreditation. Thus, the opportunity for professional societies to influence graduate programs through ABET is very limited.

The number of SE programs by category, and the number of ABET accredited programs (noted by **bold type**), are summarized in Table 3. Refer to Appendix Table 1 and Appendix Table 2 for specific programs that are accredited, also indicated there in **bold type**. Details regarding ABET programs that are accredited may be found at **www.abet.org**

Table 3. SE Programs by Category and Degree Level with Accreditation Noted.

SE Category	Number BS/**BS**	Number MS/**MS**	Number PhD/**PhD**	Number of Programs	% ABET Accredited
Systems Centric SE	11/**11**	31/**1**	14/0	56/**12**	21.4%
Domain Centric SE	44/**44**	42/**1**	23/0	109/**45**	41.3%
Totals	55/**55**	73/**2**	37/0	165/**57**	34.5%

Fifty five (55) of the 165 degree programs in Systems Engineering are at the undergraduate level, all ABET accredited. This leaves 110 SE programs at the graduate level, only two of which are ABET accredited (graduate programs in SE outnumber undergraduate programs exactly 2 to 1). Only 57 out of the 165 degree programs in SE are accredited. This is *barely more than one-third* of all SE programs in the US. This is the basis for the suggestion (in Section V) that the idea of academic program certification at the graduate level be considered.

SE Program Criteria. Criteria for the accreditation of Systems Engineering programs at the basic level are based upon the published General ABET Criteria for those institutions offering programs at this level. Institutions seeking accreditation for the first professional degree in Systems Engineering at the advanced level must meet the published General ABET Criteria for advanced level programs in addition to the basic level criteria. INCOSE fully supports the General ABET Criteria as it applies to basic level and to advanced level accreditation, recognizing that the decision to apply for accreditation review at the basic or the advanced level is to be made by the institution. Participating bodies provide the criteria and institutions choose the accreditation level to be requested.

At present, there are no program specific criteria for Systems Engineering. Thus far, SE programs have been accredited by ABET upon request under a special category. Program criteria unique to Systems Engineering will be developed by the group of participating societies for SE under the Multiple Lead Society Concept (see Section IV). This will be accomplished through the Engineering Accreditation Commission of ABET in due time and approved by the ABET Board when consensus has been reached.

Unlike many bodies that accredit academic institutions, ABET focuses on the characteristics of degree programs and the products of these programs for the purpose of enhancing quality. INCOSE has an opportunity and obligation to advance its interest in the quality of SE education by diligently supporting the mission of ABET. This is occurring through both ABET Board membership (policy) and participation in ABET program reviews (operations).

V. Systems Engineering Certification and Licensing

Certification is an occupational designation that provides confirmation of an individual's *competency* (demonstrated education, experience, and knowledge) in a specified profession or occupational specialty. Certification may also be applied to an academic program, providing a *measure of assurance* about the quality of program graduates. Certification also differs from licensing in that *licenses are permissions* granted by governmental authorities for a person to practice within its jurisdiction.

SE Certification of Individuals. Certification is a formal process issued by an organization. Certification is normally voluntary. It is neither a barrier nor a gateway to entering employment. However, it is often used as a qualifier in placement within the corporate world.

Professional certification is based on standards, often more advanced or exacting than are established by a profession itself. Certification is a formal process whereby a group of knowledgeable, experienced, and skilled representatives of an organization provides formal recognition that a person has achieved competency in specific areas as demonstrated by education, knowledge, and experience.

Within INCOSE there is the Certified Systems Engineering Professional (CSEP) program offered at three levels; Associate SEP, Certified SEP, and Expert SEP. Similar programs are available within most engineering technical and professional societies. And, like INCOSE, there often exists tension within a society between the academic membership and those from the non-academic sectors regarding the characteristics and value of professional certification.

Certification of SE Academic Programs. [11] Systems Engineering participation in the mission of ABET is necessary, but not sufficient for three reasons:

1. Only a fraction of the degree programs in Systems Engineering will continue to be offered for ABET accreditation by academic institutions,
2. The work of ABET is based principally in the United States, whereas SE graduate programs and INCOSE are rapidly expanding worldwide, and
3. Advancing graduate level SE as an international interdiscipline with world class quality is unlikely to be feasible by classical accreditation methods.

The vision for academic certification is predicated on the proposition that graduate study in Systems Engineering would produce more uniformly effective graduates if programs with certain desirable institutional and programmatic characteristics are recognized. Economically feasible web-based assessment to recognize quality outcomes could be initiated worldwide. Accordingly, certification of superb SE degree programs is being encouraged by some visionaries.

As a counterpart to professional certification of individuals, certification of Systems Engineering degree programs within academia may be timely for another important reason; What's in a Name? Academicians and practicing professionals alike are developing and applying powerful tools and methods for analysis, experimentation, modeling, simulation, etc. to the domain of operations. They permeate the fields of engineering management, industrial engineering, management science, operations research, systems analysis, and many others. The efforts and contributions of these individuals are often mistakenly considered to be Systems Engineering. These important techniques and methods are necessary, but not sufficient. SE is life-cycle process and synthesis centric and depends on all of the above for its effective execution.

Systems Engineering Licensure. Licensing differs from certification in that licenses are permissions granted by a governmental authority for a person to practice within its regulatory boundaries. Licensing differs from a "certificate" that documents the successful completion of a training or education program. It also differs from certification as described above. Happily, reciprocity of professional registration is granted among most of the states in the US.

Licensure is usually sought by engineers in those practices that directly impact public health, safety, and welfare with prime examples being civil and environmental engineering. However, a broadened view of the public interest could include SE as an important profession for professional registration. The common industrial exemption could be reconsidered for engineers responsible for outcomes regarding the viability of costly human-made systems of today.

Increasingly, progressive employers are encouraging individuals to pursue engineering licensure. Employers recognize that licensing for engineering professionals not only meets legal requirements, but also ensures that their key employees are prepared to meet national and international standards of professional practice. Disappointments with cost, schedule, and even performance aspects of large, complex, and risky technological undertakings in the public interest suggests consideration of licensure as a possible requirement for Systems Engineers.

VI. Systems Engineering Knowledge and Publications

INCOSE, like other professional and technical societies, has an obligation to advance, develop, archive, and publish a body of knowledge central to its purpose. This is being accomplished for Systems Engineering by the classical means found within all learned professions; a body of knowledge, referred journals, one or more periodicals, textbooks, and up-to-date web sites.

SE Knowledge and Curriculum (BKCASE).[12] BKCASE is a recently initiated knowledge-based project with a scope to define a SE body of knowledge (SEBoK) and then use of the SEBoK to develop a graduate reference curriculum for SE, called GRCSE. Ideally, the SEBoK will be supported worldwide by the SE community as the authoritative BoK for the SE knowledge domain. It is hoped that the GRCSE will receive global recognition and serve as the authoritative guidance for degree programs in SE, **www.bkcase.org**

Scheduled for release incrementally for comment during 2010 and 2011, SEBoK and GRCSE are scheduled for delivery in 2012. Prior work over many years provides a supporting body of material pursued under the INCOSE designation of SEBoK (SE Body of Knowledge). SEBoK processes, lessons learned, and the products and applicable standards were developed from material going as far back as the 1930s.

Neither BKCASE nor SEBoK are intended to create new work. Their purpose is to provide organization and context for information that exists. The final product has as its goal the provision of a singular resource for understanding the extent of the practice of Systems Engineering for a spectrum of purposes. Updating is planned as needed over time.

Systems Engineering Journals. INCOSE has a refereed journal entitled *Systems Engineering*, now in Volume 13 under Editor Andy Sage and twenty Associate Editors. It serves to advance and archive the art and practice of SE, relying on classical peer review procedures.

An original, single-issue, journal preceded the current refereed SE journal. Articles therein were prepared by the INCOSE Fellows and published in 1994.[13] INCOSE also publishes a quarterly entitled INSIGHT, addressing popular topics of more immediate interest. Although not refereed, this publication is of interest to many because of its professional and practice focus.

Systems Engineering Textbooks. The permanent publication of SE teaching, learning, and reference materials is now occurring with greater frequency and quality in textbooks from most major publishers. There also exists two well known book series.

The oldest series is largely domain centric and has been hosted by Pearson Prentice Hall since 1972. This is the *International Series in Industrial and Systems Engineering*, co-edited by Wolt Fabrycky and Joe Mize. Another is largely systems centric, known as the *Wiley Systems Engineering Series.* It is edited by Andy Sage and published by John Wiley and Sons.

Then there is a cluster of books in Systems Engineering published by CRC Press. This has come into being in recent years without an outside editor. And, almost all publishers are contributing individual books on Systems Engineering with encouragement from INCOSE and others.

VII. Systems Engineering Recognition and Honors

Almost all technical and professional engineering societies have internal recognition programs for members. INCOSE is no exception, having the membership designation of Fellow, the prestigious Pioneer award, distinguished service awards, chapter awards, and several others. Also, there is the three-level certification recognition described in Section V that is open to all.

Externally, each technical society has a cognizant honor society. Normally under a separate Board, these honor societies are chartered as US IRS 501(c)3 charitable and educational organizations. Most are tied very closely to academia, specifically to those academic institutions that offer degree programs in the special area of the technical society.

Omega Alpha Association (OAA), the Systems Engineering Honor Society, is being established internationally to identify, recognize, and honor distinguished individuals who have internalized and are promulgating the philosophy of da Vinci; *think about the end before the beginning.* An overview of OAA and its current status is available on **www.omegalpha.org**

The overarching objective of the Omega Alpha Association is to advance the Systems Engineering process and its professional practice in service to humankind. Among subordinate objectives are opportunities to:

1. Inculcate a greater appreciation within the engineering profession that every human design decision shapes the human-made world and determines its impact upon the natural world and upon people.
2. Advance system design and development morphology through a better comprehension and adaptation of the da Vinci philosophy of thinking about the end before the beginning; that is,

determining what designed entities are intended to do before specifying what the entities are, and concentrating on the provision of functionality, capability, or a solution before designing the entities per se.
3. Encourage excellence in Systems Engineering education and research through collaboration with academic institutions and professional societies to evolve robust policies and procedures for recognizing superb academic programs.

The Omega Alpha initiative began with the a few distinguished SE visionaries and is expanding slowly to include others of quintessential stature. OAA is concentrating currently on the doctoral degree category of programs in academia. Current plans are to establish an initial presence in academia by selecting, recognizing, and honoring graduate professors and mentors with truly outstanding records, together with superb doctoral students.

VIII. Systems Engineering Status and Maturity

Engineering education has been subjected to in-depth study every decade or so, beginning with the Mann Report in 1918.[14] The most recent and authoritative study was conducted by the National Academy of Engineering (NAE) and published in 2005 under the title, *Educating the Engineer of 2020.*[15]

Engineering in the 21st Century. Although acknowledging that certain basics of engineering will not change, this NAE report concluded that the explosion of knowledge, the global economy, and the way engineers will work will reflect an ongoing evolution that gained momentum at the end of the twentieth century. The report gives three overarching trends to be reckoned with by engineering educators, interacting appropriately with engineering leaders in government and industry:

1. The economy in which we work will be strongly influenced by the global marketplace for engineering services, evidenced by the outsourcing of engineering jobs, a growing need for interdisciplinary and system-based approaches, demands for new paradigms of customization, and an increasingly international talent pool.
2. The steady integration of technology in our public infrastructures and lives will call for more involvement by engineers in the setting of public policy and for participation in the civic arena.
3. The external forces in society, the economy, and the professional environment will all challenge the stability of the engineering workforce and affect our ability to attract the most talented individuals to an engineering career.

SE Maturity for the 21st Century. Systems Engineering enters the 21st Century well positioned to contribute to the advancement of society. Continuing technological advances have created an increasing demand for engineers in most fields. But certain engineering and technical specialties will be merged or become obsolete with time. There will always be a demand for engineers who can synthesize and adapt to changes. The astute engineer should be able to detect trends and plan for satisfactory transitions by acquiring knowledge to broaden his or her capability.

It is encouraging to note that most schools and colleges of engineering are continually evolving their course offerings and degree requirements. Faculty members and administrators from these institutions meet periodically with corporate and governmental leaders to discover and consider changing needs. This same propensity compels most to seek formal peer approval in the form of programmatic accreditation through ABET, albeit limited to the undergraduate level.

Another sign of maturity is the ABET outcomes approach for the accreditation of academic programs. Instead of assessing the quantity and characteristics of input ingredients, ABET now relies on the academic institutions to set criteria for the output capability of graduates. These criteria will be developed for SE by collaboration among interested ABET participants.

Systems Engineering has experienced rapid growth in the commercial and governmental sectors. The need for Systems Engineering talent has increased beyond the available supply, and forward-looking enterprises and governmental agencies are increasingly helping to alleviate the problem through research, industry-academic collaboration, and advisory bodies.

IX. Summary and Conclusions

Systems Engineering entered this decade with considerable momentum. A maturing professional society and degree programs at all levels are probably the most tangible and visible connections between practicing professionals, academic institutions, and private and public enterprises.

The classification of Systems Engineering degree programs that originated in 2005 is updated within this paper; Systems Centric SE and Domain Centric SE. This classification is now populated by 165 degree programs that are offered by 80 academic institutions. Understanding and insight into the complexity of Systems Engineering academic degree programs would be difficult without use of this classification.

An increase occurred in the number of undergraduate DCSE programs and also in graduate programs within both the DCSE and SCSE categories. But, the number of undergraduate SCSE programs remained the same. Of greater interest is the fact that SE accreditation by ABET is *influencing just one-third* of all Systems Engineering degree programs in the US. Thus it is suggested that the idea of academic program certification for graduate programs be considered.

The Systems Engineering knowledge base and curricula are now in greater focus due to the BKCASE initiative. Beyond its potential benefit to provide guidance for graduate degree programs, is its possible use in the preparation of individuals for certification and licensing. At the same time, refereed journals and textbooks in SE are rapidly expanding and improving.

Since continuing study and professional practice are life-long and cross most geographic and professional boundaries, with the workplace being anywhere on the globe, all engineers should embrace and utilize *systems thinking*. Likewise, systems thinking should be applied to the academic and professional process of Systems Engineering itself. The emergence and status of SE as a profession, among the engineering professions, is worthy of continuous examination.

The author affirms that most of the ideas and priorities for SE advancement in this paper are his. Accordingly, he invites academicians and practicing professionals to apply their systems thinking about how best to advance the emerging attributes of Systems Engineering; **fab@vt.edu**

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APPENDIX

Two tables are presented in this Appendix. The first is for Systems Centric SE programs and the second for Domain Centric SE programs. Institution and degree program information was obtained from *Peterson's Guide to Programs in Engineering and Applied Science* [16], from the ABET web site **www.abet.org**, from the INCOSE web site **www.incose.org**, and from other sources. ABET accredited degree programs are indicated in the tables by **bold face** type.

Appendix 1. Systems Centric Systems Engineering (SCSE) Programs

Institution	Degree Programs
Air Force Institute of Technology	**MS**, PhD in Systems Engineering
Boston University	MS, PhD in Systems Engineering
Case Western Reserve University	**BS**, MS, PhD in Systems & Control Engineering
Colorado State University	ME in Systems Engineering
Cornell University	ME in Engineering, Systems Engineering Option
George Mason University	**BS**, MS, PhD in Systems Engineering
George Washington University	MS, PhD in Systems Engineering
Iowa State University	ME in Systems Engineering
Johns Hopkins University	MS in Systems Engineering
Lehigh University	**BS**, MS in Information & Systems Engineering
Massachusetts Institute of Technology	PhD in Engineering Systems
Missouri University of Science & Technology	MS, PhD in Systems Engineering
Naval Postgraduate School	MS in Systems Engineering
Pennsylvania State University	ME in Systems Engineering
Polytechnic University - Farmingdale	MS in Information Systems Engineering
Portland State University	ME in Engineering, Systems Engineering Option
Rochester Institute of Technology	ME in Systems Engineering
Southern Methodist University	MS, PhD in Systems Engineering
Southern Polytechnic State University	MS in Systems Engineering
Stevens Institute of Technology	ME, PhD in Systems Engineering
United States Air Force Academy	**BS** in Systems Engineering
United States Military Academy	**BS** in Systems Engineering
United States Naval Academy	**BS** in Systems Engineering
University of Alabama - Huntsville	MSE, PhD in Systems Engineering
University of Arizona	**BS**, MS in Systems Engineering
University of Arkansas - Little Rock	**BS** in Systems Engineering
University of Houston - Clear Lake	MS in Systems Engineering
University of Idaho	ME in Systems Engineering
University of Maryland	MS in Systems Engineering
University of Michigan	PhD in Information Systems Engineering
University of Pennsylvania	**BSE**, MSE, PhD in Systems Science & Engineering
University of Southern California	MS in Systems Architecture & Engineering
University of Texas - Arlington	MS in Systems Engineering
University of Texas - San Antonio	MS in Systems Engineering
University of Virginia	**BS**, MS, PhD in Systems Engineering
Virginia Tech	MS in Systems Engineering
Washington University	**BS**, MS, PhD in Systems Science & Engineering

Appendix 2. Domain Centric Systems Engineering (DCSE) Programs

Institution	Degree Programs
Arizona State University	**BS** in Computer Systems Engineering
Auburn University	**BS** in BioSystems Engineering MS in Manufacturing Systems Engineering MS, ME, PhD in Industrial & Systems Engineering
Boston University	**BS**, MS in Computer Systems Engineering
California State University - Northridge	**BS** in Manufacturing Systems Engineering
Colorado State University - Pueblo	MS in Industrial & Systems Engineering
Florida A&M University	**BS** in Biological & Agricultural Systems Engineering
Florida International University	**BS** in Industrial & Systems Engineering
Lehigh University	PhD in Industrial & Systems Engineering
Michigan State University	**BS** in BioSystems Engineering
New Jersey Institute of Technology	MS in Manufacturing Systems Engineering
North Carolina A&T University	**BS** in Industrial & Systems Engineering
North Dakota State University	**BS**, MS in Agricultural & BioSystems Engineering
Northeastern University	MS, PhD in Computer Systems Engineering
Northern Illinois University	**BS**, MS in Industrial & Systems Engineering
Oakland University	**BS**, MS, PhD in Industrial & Systems Engineering
Ohio State University	**BS**, MS, PhD in Industrial & Systems Engineering
Ohio University	**BS**, MS, PhD in Industrial & Systems Engineering
Oklahoma State University	MS in Industrial & Manufacturing Systems Engineering **BS**, MS, PhD in BioSystems Engineering
Purdue University	PhD in Manufacturing & Production Systems Engineering
Rensselaer Polytechnic Institute	**BS**, MS, PhD in Industrial & Systems Engineering **BS**, MS, PhD in Computer & Systems Engineering
San Jose State University	**BS**, MS, PhD in Industrial & Systems Engineering
South Dakota State University	**BS**, MS in Agricultural & BioSystems Engineering
Stanford University	MS in Manufacturing Systems Engineering
State University of NY - Binghamton	**BS**, MS, PhD in Systems & Industrial Engineering
Texas A&M University	**BS**, MS, PhD in Biological Systems Engineering
Texas Tech University	MS in Manufacturing Systems & Engineering
University of Alabama - Huntsville	**BS**, MS, PhD in Industrial & Systems Engineering
University of Alaska	**BS**, MS, PhD in Computer Systems Engineering
University of Arizona	**BS** in BioSystems Engineering **BS** in Computer Systems Engineering PhD in Systems & Industrial Engineering
University of California - Davis	**BS**, MS, PhD in Biological Systems Engineering
University of Central Florida	MS in Systems Engineering & Management
University of Florida	**BS**, MS, PhD in Industrial & Systems Engineering
University of Hawaii - Manoa	**BS** in BioSystems Engineering

University of Houston	MS in Computer & Systems Engineering
University of Houston – Clear Lake	**BS** in Computer Systems Engineering
University of Idaho	MS in Biological Systems Engineering
University of Kentucky	**BS**, MS, PhD in BioSystems Engineering
University of Massachusetts	**BS** in Computer Systems Engineering
University of Michigan - Dearborn	**BSE,** MSE in Industrial & Systems Engineering MSE in Manufacturing Systems Engineering
University of Minnesota	**BS** in Biosystems & Agricultural Engineering **BE** in Bioproducts & BioSystems Engineering
University of Nebraska - Lincoln	**BS**, MS in Biological Systems Engineering
University of Pittsburgh	MS in Manufacturing Systems Engineering
University of San Diego	**BS**, MS in Industrial & Systems Engineering
University of South Florida	**BS**, MSE in Industrial & Management Systems Engineering
University of Southern California	**BS**, MS, PhD in Industrial & Systems Engineering
University of St. Thomas	**MS** in Manufacturing Systems Engineering
University of Tennessee	**BS** in BioSystems Engineering
University of Wisconsin	**BS** in Biological Systems Engineering
Virginia Tech	**BS**, MS, PhD in Biological Systems Engineering **BS**, MS, PhD in Industrial & Systems Engineering
Washington State University	**BS**, MS, PhD in Biological Systems Engineering
Wright State University	**BS**, MS in Industrial & Systems Engineering
Youngstown State University	**BE**, MS in Industrial & Systems Engineering

Biography

Wolter J. Fabrycky, Lawrence Professor Emeritus of Industrial and Systems Engineering at Virginia Tech and Chairman, Academic Applications International, Inc. Registered Professional Engineer in Arkansas (1960) and Virginia (1965). Ph.D. in Engineering, Oklahoma State University (1962); M.S. in Industrial Engineering, University of Arkansas (1958); B.S. in Industrial Engineering, Wichita State University (1957). Taught at Arkansas (1957-60) and Oklahoma State (1962-65) and then joined Virginia Tech in 1965. Served as Founding Chairman of Systems Engineering, Associate Dean of Engineering, and then as University Dean of Research over a period of 12 years. Received the Lohmann Medal from Oklahoma State for Outstanding Contributions to ISE Education and Research (1992) and the Armitage Medal for Outstanding Contributions to Logistics Engineering Literature (2004). Received the Holtzman Distinguished Educator Award from the Institute of Industrial Engineers (1990) and the Pioneer Award from the International Council on Systems Engineering (2000). Founder (2005) and President of the Omega Alpha Association: the Systems Engineering Honor Society and President of Alpha Pi Mu: the Industrial Engineering Honor Society (2010-12). Elected to the rank of Fellow in the American Association for the Advancement of Science (1980), the American Society for Engineering Education (2007), the Institute of Industrial Engineers (1978), and the International Council on Systems Engineering (1999). Served or serving on the Boards of ABET, APM, ASEE, IIE, INCOSE, and OAA. Co-author of six Prentice Hall textbooks and Editor of the Pearson Prentice Hall International Series in Industrial and Systems Engineering.