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Title: The Case for Evolving Systems Engineering as a Field within Engineering Systems

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The Case for Evolving Systems Engineering as a Field within Engineering Systems

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Abstract
Engineering Systems is emerging as an important new field of study focusing on the complex engineering of systems in a broad human, societal, and industrial context. It takes an integrative holistic view of large-scale, complex, technologically-enabled systems which have significant enterprise level interactions and socio-technical interfaces. The establishment of this new field provides a significant step toward evolving the holistic engineering-management-policy science needed to address the complex systems challenges of this century. Systems Engineering, as a field of study, is viewed by the authors as an essential field that effectively lies within this larger field. We view *engineering systems*[1], and the positioning of *systems engineering* as one of its subfields, as having significant positive impact on developing future systems leaders who will be prepared to address the most complex engineering challenges of this century.

1.0 Introduction

Engineering as a field of study is beginning to undergo significant change in response to many complex factors including global environment, advancing technologies, complex societal needs, and new knowledge (Rhodes, 2003). With these broad changes, the field of systems engineering is evolving, and its future value and effectiveness is dependent upon the overall context in which this evolution takes place. In this paper, we discuss the emerging field of *engineering systems,* and propose that *systems engineering* as a field of study fits naturally as a embedded subfield of *engineering systems*, and that this positioning of "field within a field" is essential to effectively evolving each to address contemporary systems challenges.

In this modern world, we live supported in a complex interconnected set of overlapping systems. From birth through death, inhabitants of developed societies interact with one system or another. These systems range from health care systems to financial systems to transportation systems to information systems. As an example, the US Government has identified several critical infrastructures that underlie an advanced society: communications infrastructure, a water infrastructure, an energy infrastructure and financial services. Many of the contemporary complex systems, while important to our effective functioning, are not fundamentally the province of engineers. While having a reliance on technology, some systems are primarily social systems in that they involve how societies choose to treat their citizens. They have been analyzed through the lens of policy and economics combined in both cases with developing scientific understanding of how our bodies function and our minds learn.

Increasingly we also interact with a class of systems which depend, for their existence, on a technology or technological artifacts; these are the province of *engineering systems*. These systems provide much of the functioning of modern society. Examples include the global air traffic control system, the worldwide Internet, the worldwide communications grid and the national mobility system composed of automobiles, trains, planes, highways, train stations and airports. These systems have critical technological pieces but also have significant enterprise level interactions and socio-technical interfaces which influence the design or operation of the system. Of course many of these systems are

[1] Italics are used in the paper for *engineering systems* and *systems engineering* to indicate that we are referring to the respective fields of study, including its theory, principles, practices, and methodologies.

now being connected to each other to form a *systems of systems*. For example, the air traffic control system, the communications system and the mobility system all have inter-connections with each other.

Large scale complex systems are analyzed partly through the tools of operations research, systems analysis and economics, and designed using the processes of system engineering. The engineering management techniques for the creation of these systems have often been ad-hoc while the policies that govern the use of these systems have often emerged after the fact. The budgeting for these systems is largely an art and thus, many of these large complex systems are over budget and schedule and have initially surprising societal consequences. Witness the use of the Internet for spam, and the interaction between this emergent use and the technical design of the Internet. This advanced degree of complexity drives the need for the development of a holistic view of these systems which takes into account all the multiple facets and issues associated with them.

This integrative holistic view of technologically enabled systems is what the field of *engineering systems* is concerned with. In modern academic engineering with its large and valuable emphasis on the applied science behind engineering, this integrative view has often been neglected or underachieved since it cuts across many disciplines. Of course, this is because much of the power behind the engineering science approach lies in a reductionist mindset combined with the sharp manipulative power of mathematics. Fully appreciating these complex interconnected systems requires an integrative holistic view that combines traditional engineering approaches with insights from management and social science. The ultimate goal of this combination of disciplines in a field should be to understand, model, and predict (at least to some degree) the behavior of these complex systems in their full contexts, ensuring the engineering outcome is an evolvable, sustainable system that meets societal need.

Systems Engineering is a field with over a fifty year history of being applied to "modern day" systems, and its scope has been expanding in an attempt to comprehensively address all of the elements and issues inherent in an engineering system. We are now seeing *complex systems engineering* emerging to address the challenges that are not possible to address through *traditional systems engineering,* and that both are needed for evolvable and sustainable systems of systems. Significant study and research is ongoing to develop *complex systems engineering*, which will involve new ways of thinking about very large scale systems and associated principles, practices, and innovations in enabling technologies. We argue that each is appropriately placed as a field within the larger context field of *engineering systems*, and that this logical placement will benefit the further evolution of all.

In this paper, we focus on three discussion areas. The first is to introduce and discuss the projected future intellectual development of the field of ***engineering systems***. The second is the case for placing ***systems engineering*** as an essential subfield within *engineering systems* while retaining its individuality as an important engineering field of its own. Finally, we describe our perspective on how these fields will enable the development of engineering systems leaders, along with the required changes to present engineering education are necessary to realize this vision.

2.0 THE FIELD OF SYSTEMS ENGINEERING

The question often arises when *engineering systems* is introduced to systems practitioners, educators, and researchers, "what is the difference between *systems engineering* and *engineering systems*?" The response to this question is highly dependent upon the beholder's view of the field of systems engineering. The authors acknowledge that *systems engineering* can be and often is viewed quite differently by domains of practice and by its individual stakeholders. Since *complex systems engineering* is not well formalized nor agreed upon at present, we focus this paper on *traditional systems engineering* which involves the engineering of products and systems having clear boundary conditions, well specified requirements, and adequately understood performance parameters. A future paper will discuss the relationship of *complex systems engineering* and *engineering systems*.

Systems engineering has many definitions, and we can see the variation by looking at extremes of these views of *traditional systems engineering* (henceforth referred to as systems engineering) field today – which we will refer to as 'classical view' versus the 'expanded view'. We examine how each view of *systems engineering* is contrasted with *engineering systems*, and argue that no matter which perspective is taken, the latter is broader than the former. We assert that the evolution of *systems engineering* as a field within the larger field of *engineering systems* can enrich the global practice of engineering and benefit stakeholders of complex technology-enabled systems. The debate on the definition of *systems engineering* has been ongoing for several decades without conclusion, and we have yet to find our way out of what has been described by Brill (1994) as a "semantics jungle". We believe that placing the field in the context of *engineering systems* will help to end this debate by providing the much needed larger context field in which it can be viewed. In this sense, this is like the mathematical technique of "embedding" where broadening of the context of a problem enables the solution to be seen.

Classical systems engineering is focused on the processes for moving from requirements to a design for a system (product). It is not fully suited for dealing with the global and socio-technical aspects of the 21st century systems, and it does not adequately address the enterprise as part of the overall system. Classical systems engineering principles and practices need to be adapted and expanded to fully support the engineering of highly complex systems. Taking an expanded view (including the full lifecycle perspective, systems architecting, and systems management) seeks to solve these inadequacies but does not fully address the enterprise and engineering ecosystem aspects of large scale systems. In this paper, we explore what distinguishes the engineering systems perspective from the systems engineering perspective, and how this embedding approach to these two fields contributes to transformation of engineering to more effectively address the technologically based challenges of this century. One important point that needs to be made explicit is that *engineering systems* does not replace *systems engineering*, which is an important field in its own right providing the fundamental process and methods for design and development of the product system.

The field of *systems engineering* has existed much longer than the emerging field of *engineering systems* and this would lead one to conclude that there is an accepted standard definition. In reality, the number of definitions of has increased significantly over the past decade or more. Classical definitions arose in the 1960s and 1970s, and are still widely in use today. The classical definitions are fairly similar in nature, with some variation regarding reference to it as a practice, process, method, or approach. An example of a definition taking the classical view is:

> *Chase (1974) – Systems Engineering is the process of selecting and synthesizing the application of the appropriate scientific and technical knowledge to translate system requirements into system design* a*nd subsequently to produce the composite of equipment, skills, and techniques that can be effectively employed as a coherent whole to achieve some stated goal or purpose.*

Over the past two decades, an expanded view of *systems engineering* has emerged that takes it beyond the transformation of requirements to design as its core focus. This expanded view has a full lifecycle perspective and includes socio-technical factors as considerations in the engineering process. There are many varied definitions for the "expanded" systems engineering; we offer three as examples:

1. *Ramo (1984) – Systems Engineering is a branch of engineering that concentrates on the design and application of the whole as distinct from the parts…looking at the problem in its entirety, taking into account all the facets and variables and relating the social to the technical aspects.*
2. *INCOSE (1996) -- Systems Engineering is an interdisciplinary approach and means to enable the realization of successful systems.*
3. *Kossiakoff & Sweet (2003) – The function of Systems Engineering is to guide the engineering of complex systems. Systems Engineering is focused on the system as the whole – it emphasizes total operation. It looks at systems from the outside, that is, at its interactions with other systems and its environment, as well as from the inside.*

2.1 Criticisms of Systems Engineering

The fundamental definition and scope of *systems engineering* continue to be debated, particularly as the field moves into domains and interest areas which introduce added diversity in the nature of systems, system stakeholders, and associated practitioners. Variances in definitions and boundaries of *systems engineering* can lead to misunderstandings between system stakeholders regarding roles, functions, and authorities. When taking a classical view, a major fault cited with systems engineering is that it does not take an adequate holistic perspective and is too introspective. Additionally, it is often viewed as taking too much of a top-down approach. The field has been criticized for being too focused on processes and not enough on the systems themselves. Further, it is sometimes criticized for focusing too extensively on requirements and not enough on the system's properties and behaviors. And, because of its history, the field is seen as weighted to an "aerospace view" of systems, yet it is just as prevalent in public works projects, commercial products, and information systems.

Another highly debated issue concerns the value it contributes to the acquisition, development, and sustainment of systems. An often cited shortfall is the lack of quantitative data to show this value; seven published efforts to date focus only at the macro level. This lack of a quantified value proposition has led to some programs in the nineties having systems engineering resources cut from the program, with the attendant damage only becoming evident much later on. Recent initiatives by INCOSE, NASA, and others are attempting to collect and document the evidence to demonstrate the value of *systems engineering* on a project, but these fall short of the comprehensive detailed study that is needed as this involves significant investment to accomplish (Honour, 2004).

Systems engineering assumes that the parameters related to system context and environments are constraints, and this can result in system failures and shortfalls. For example, a policy that impacts the system will be viewed as fixed for the purposes of designing a solution. This can lead to system failures if such parameters are not taken as variables at some appropriate point in the system lifecycle. An illustrative case for the need for considering policy changes when beginning a systems effort is a case study by Buede (1998) on the failure of the initial air bag design as related to safety standards.

The strongest heritage of *systems engineering* comes from the aerospace and defense industries, and the terminology and language of these industries can put artificial boundaries and constraints around it as a discipline and practice. Other domain areas such as telecommunications or public works projects may practice some of the same activities, however the terminology and flow of these activities varies and leads to a separation between the various "engineering domain cultures". Another key issue with the present practice is that it is often applied at the subsystem level, sometimes applied at the higher systems level, but rarely applied at the system-of-systems or extended enterprise level. An issue in its successful application, particularly in defense programs, is that its organizational placement under program management results in system performance, operational effectiveness, and human-system requirements traded for cost and schedule.

3.0 THE FIELD OF ENGINEERING SYSTEMS

The field of *engineering systems* is continuing to evolve through dialogue within the MIT community, between MIT and other universities, and between MIT and its industry and government partners. For the purposes of this paper, we present the following short definition to describe to the reader the emerging field: *Engineering Systems is a field of study taking an integrative holistic view of large-scale, complex, technologically-enabled systems with significant enterprise level interactions and socio-technical interfaces.* We refer the reader to foundational papers by MIT authors[2] for an elaborated definition and description, along with additional discussions of research within this new field. The proceedings of a major symposium, the Engineering Systems Symposium, held March 2004, include discussion of this field by experts from industry, governments, and other universities[3]. Following this event, a coalition of interested universities joined together as the University Coalition on Engineering Systems (UCES) to collaborate on the intellectual foundations and research agenda for *engineering systems*.

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[2] Refer to MIT Engineering System Division's website for many papers: http://esd.mit.edu/WPS/wps.html

[3] Refer to the MIT Engineering Systems Symposium webpages for talks, monographs, and technical papers: http://esd.mit.edu/symposium/agenda.htm

3.1 Systems of Interest for Engineering Systems

The definition of a system is a collection of pieces whose collective functioning is greater than the functioning of the individual pieces. Within the mathematically based rigorous engineering and scientific world this vagueness has led to some criticism since it is so broad. If "systems" applies to everything then it also applies to nothing, thus in order for us to be specific we focus on the types of systems that are engineered systems. Our definition of the systems of interest within the field of *engineering systems* is quite specific, and will lead us to the consideration of the kinds of people who will need to be developed in order to effectively address these systems. In this field, we are interested in systems with the following characteristics:

- Technologically enabled
- Large scale (large number of interconnections and components)
- Complex
- Dynamic, involving multiple time scales and uncertainty
- Social and natural interactions with technology
- Likely to have emergent properties

The phrase "technologically enabled" applies to systems for which one or more artifacts of technology are at their core. That is, the systems would not exist apart from the technological artifact(s). A good example is the air traffic control system which has at its core, airplanes, radars and airports. The systems we are interested in understanding are also large in the sense of having a large number of interconnections. This may map to large physical scale (it clearly does for an air traffic control system) but it does not necessarily have to do so (for example, one cannot imply any physical scale to the internet but it has a large number of interconnections). The description of engineering systems as *complex* is meant to imply that they have nonlinear properties in that the outputs of the system are not simply related to the inputs. In part, this nonlinear behavior flows from having underlying multiple timescales in the system coupled with the overwhelming presence of uncertainty. In part, it also flows from the fact that the systems we are interested in have significant pieces and decisions determined by the interaction of the systems with the social world or natural world. Finally, we observe that these systems often have emergent properties usually in the usage or in the response of society to these systems. For example, the current use of the Internet for spam was not at all predicted or understood when the underlying technical architecture of the Internet (which makes it easy) was laid down.

We argue that understanding *engineering systems* requires four unique perspectives which take it beyond the perspectives taken by the field of *systems engineering,* as evidenced by the historical criticisms of the field. First, it involves a much **broader interdisciplinary perspective**, embracing technology, management science and social science. Secondly, engineering systems involves an **intensified incorporation of system properties** (such as sustainability, safety and flexibility) in the design process. Note that these are lifecycle properties rather than first use properties. These properties, often called "ilities" emphasize important intellectual considerations associated with long term use of engineering systems. These may be quite different from the first use for which the systems were designed, and may come to dominate the use of the systems. Third, this new field **emphasizes the enterprise perspective**, acknowledging the interconnectedness of the product system with the enterprise system that develops and sustains it. This involves understanding, architecting and developing organizational structures, policy system, processes, knowledgebase, and enabling technologies as part of the overall engineered system. The fourth perspective is a **complex synthesis of stakeholder perspectives**, of which there may be conflicting and competing needs which must be resolved to serve the highest order system (system-of-system) need.

One of the best ways to understand the systems of interest in the field of *engineering systems* is by example. Important examples of such systems include:

- Military Aircraft Production & Maintenance Systems
- Commercial & Military satellite constellations

- Mega-city surface transportation systems
- Worldwide Air Transportation & Air Traffic Control System
- Automobile Production & Recycling Systems
- Consumer supply logistics networks
- Electricity generation & transmission system

These systems are all manifestly technologically enabled, have significant socio-technical interactions and have substantial complexity. It is also the case that to varying degrees an understanding of them requires an understanding of the enterprises that constructed them or within which they operate.

3.2 Embedded Subfields of Engineering Systems

The development of any field of study requires progress in the underlying disciplines, or subfields. For example, the development of progress in fusion energy engineering has required progress in the underlying discipline of plasma physics. The four underlying subfields for engineering systems are:

1. Systems Engineering (including systems architecting and product development);
2. Operations Research and Systems Analysis (including system dynamics);
3. Engineering Management; and
4. Technology & Policy.

And, it is the intersection of these four subfields around the system applications that will lead to greater understanding of the field of engineering systems. Further, these are applied to both the product system and the enterprise system in context of an overall engineering environment or ecosystem.

One way to consider the intersection of these disciplines around a complex engineering system is to consider a specific example like the National Missile Defense (NMD) system. The NMD system first needs to be architected (taking into account both legacy systems as well as emerging technologies and techniques for detection) and then detailed systems engineering performed. It will be analyzed with the techniques of operations research (including game theory) and systems analysis. It will be built by large organizations whose organizational dynamics will play a role in the architecture, choice of partners, order in which pieces are designed and constructed. Finally, the design choices have interesting and significant policy implications that will affect the initial set of architectural choices. Thus, issues of technology and policy are critical to the design and operation of this system. The following briefly explores what needs to be done in advancing each subfield, in the engineering systems context.

Systems Engineering, Systems Architecting, and Product Development. Systems engineering and product development involve a set of well-defined, structured processes whereby a design can be taken from the statement of requirements to a specific manifestation. Systems architecting describes the larger process whereby concepts are developed that map desired function to form, which may undergo the process of systems engineering. While *systems engineering* has undergone considerable development, the development of systems architecting is in its infancy. This is still largely an art whereby architects inductively develop concepts to satisfy expressed needs. Much of the further intellectual development that is needed here will come from the quantification and manipulation of system architectures (Whitney et al, 2004). Systems engineering is undergoing rapid transformation as the techniques of model based systems come into play, and this advancement will be central to having the capability to model and visualize large complex systems before they are developed. Research is also critically important to understand how to design for flexibility, agility, scalability, robustness and other properties. Developing a *complex systems engineering* approach and methodologies suited to systems of systems and enterprises is presently an area of considerable study and research.

Operations Research and Systems Analysis. Operations Research has highly developed the theory of optimization for different types of cost functions. In a similar vein, various systems analysis techniques have been developed to analyze the behavior of systems once they can be reduced to quantifiable networks. Both of these areas need further development to fully address the issues of complex engineering systems. Operations Research needs to develop an understanding of the nature of optimization when lifecycle issues are important as well as when issues of flexibility need to be quantified. In this, there is significant development that can be undertaken using the techniques of financial engineering particularly real options as a way to value flexibility (deNeufville et al, 2004) and technology valuation (Shishko, et al, 2004).

Systems analysis has developed the macroscopic technique of *system dynamics* (Sterman, 2000), a powerful way to model many kinds of engineering systems. While it produces many insights it often comes down to understanding what the coefficients are that relate the stocks and the flows. A newer analysis methodology that offers great potential is *agent based modeling* whereby systems are modeled at much more elemental level and a complex set of interactions is built from a simple set of rules. The development of analysis techniques for engineering systems will need to integrate these modeling techniques to form an operational palette for the engineering systems analyst.

Engineering Management. The complexity of engineering systems brings new challenges to how we manage large scale efforts. It involves the synthesis of highly complex stakeholder needs, often tuned to a system providing a unique standalone capability, while also needing to collaborate with other systems to provide a larger system-of-systems capability. The need for central control of highly complex systems (with decentralized execution) is introducing a new role for a *lead systems integrator*, involving the need to serve in a more neutral broker role and to make difficult decisions that may appear suboptimal at the component system level. The approaches and methods for acquisition and management will need to evolve to accommodate both the technical complexities as well as the enterprise complexities. All real engineering systems are built within enterprises and operated within society. The interaction between the architecting/designing of the enterprise and the engineered (product) system is deep, with significant co-influence. While organizational theorists have well developed theories of how organizations function and make decisions, this understanding needs to be integrated into the design phase in a quantifiable way. This vision is that a priori the effect of the enterprise organization on the engineering system will be predictable to some degree rather than being an unanticipated emergence (Allen, et al, 2004).

Technology and Policy. The large scale systems of interest in the study of engineering systems share the property that there are significant socio-technical interactions. Too often these interactions have been observed after the systems have been designed and considerable resources have been spent. The thoughtful analysis of these interactions has also been the realm of political scientists or sociologists. The development of engineering systems will have these interactions modeled in a way that is both qualitative and quantifiable, and can be included in the systems analysis of these complex systems (Dodder and Sussman, 2003).

3.3 Enterprise Science and Engineering Systems

Effectively engineering complex systems requires us to consider the enterprise system and product system as intimately interconnected. Enterprises are complex, highly integrated systems comprised of organizations, processes, policies, information and enabling technologies, with multifaceted interdependencies and interrelationships across their boundaries. Understanding, managing, and transforming these complex social, technical, and infrastructure dimensions are critical to achieving and sustaining enterprise performance. Further, in highly complex systems of systems, the synergistic architecting and evolution of product system (s) and associated enterprise becomes even more critically important as the dependencies and co-influence increase exponentially.

The question of how consideration of the enterprise fits with systems engineering is again best considered by differentiating the classical and expanded views. In classical systems engineering, the enterprise is typically referred to as the external environment. It imposes constraints (requirements, rules, regulations, policies, standards) on the system that are generally thought of as fixed and non-changeable. Minimal consideration is given to the enterprise during the systems engineering of the product system, except to design to accommodate the constraints as specified in the requirements, and ensuring the needs of the enterprise primary stakeholders (customer and end users) are considered.

As systems engineering evolves to the expanded (full lifecycle) view, the consideration of the enterprise increases in importance. The term *enterprise* becomes a key part of the vocabulary of the systems engineering lexicon. What traditionally was illustrated as a solid boundary line in a systems context diagram has become of central interest to systems engineering, and new techniques have emerged to describe the enterprise aspects of the overall engineering system. Now it is typical for a systems engineering plan to include the enriched description of the elements of the enterprise including customer, prime contractor, suppliers, processes, policies, tool environments and so forth. Constraints imposed by the enterprise are described in detail, and plans to comply with these constraints are fully elaborated in systems engineering plans and specifications. Integrated capability maturity models set the best practice standards for excellence in the complex enterprise.

In recent years we are seeing two major trends that are directed at enriching our understanding of the enterprise for the purposes of developing better systems. The first of these is the evolution of the field of enterprise architecting from a limited, IT centric field to one that considers the enterprise from a holistic perspective. With the growing complexity of systems, there is a corresponding increase in the complexity of the enterprises that develop, operate, and sustain such systems in an increasingly global environment. This drives the need to take a broader view of enterprises as systems in themselves to which we must apply the principles and practices of architecting. The current practice of enterprise architecting has been a significant contribution to creating and sustaining modern enterprises; however, the current field is not a sufficient approach to the enterprises of this new century. A broader and more holistic approach is needed in context of an engineering systems perspective, drawing on the emerging systems architecting field, and taking into account new paradigms and environmental drivers. Nightingale and Rhodes (2004) describe *enterprise systems architecting* as an emerging art and science within the overall field of *engineering systems,* involving a more strategic approach which takes a systems perspective, viewing the entire enterprise as a holistic system encompassing multiple views including policy view, organization view, process view, knowledge view, and enabling technology view in an integrated manner. This expanded viewpoint is the subject of research at many leading universities today, and builds on early work in the field, for example, Rechtin, (2000) who proposed the principles of systems architecting as extensible to architecting organizations.

The contemporary architectural description of enterprises can be quite comprehensive. Multiple views of an enterprise are now well enumerated, and there are numerous enterprise architecture frameworks. These frameworks serve to ensure the enterprise architecture is fully described from its multiple perspectives and that this information is communicated to all the stakeholders for defining, developing, and sustaining the system. Along with these frameworks, we see many new toolsets for modeling the enterprise which have come into the market. Complex systems are being modeled using these toolsets for both product and enterprise. There are limits to the frameworks; however, as we move into the system of systems realm, for example, these lack the ability to describe such concepts as layering. It should be noted that the frameworks provide for descriptions of views of the architecture; they are not the architecture.

With large scale, complex engineering systems comes the need to merge the systems engineering and enterprise engineering practices, as *enterprise systems engineering.* This new approach involves applying the principles of systems engineering to the enterprise itself, as a complex entity including the product system(s). It involves many different engineering projects which co-exist and evolve, each with its own unique lifecycle. In taking an engineering systems perspective, we recognize that the product system and the enterprise system are intimately connected. The architecture of a future product system and the architecture of the enterprise which will design and produce it must be in harmony to achieve optimal results. Enterprise systems engineering will further expand systems engineering to a larger footprint within *engineering systems.*

3.4 Understanding of Complex Engineering Systems

Given the systems of interest in the engineering systems field, we turn to explore the current state of our understanding. The well-known hierarchy of knowledge by which we can explore our understanding is:

1. Observation
2. Classification
3. Abstraction
4. Quantification and Measurement
5. Symbolic Representation
6. Symbolic Manipulation
7. Prediction

Many engineering fields have started out at level one (observation) and moved to level seven (prediction). A good example is the discipline of what we now call thermodynamics. This started with observations of steam engines which were made to work by a trial and error process. As time progressed, various laws were discovered. Eventually, the laws of classical thermodynamics were deduced which allowed engineers to move to level seven (prediction) for thermodynamic engines. It was realized that the three laws of thermodynamics under-girded all the previous observation and allowed new types of machines to be constructed. This is also true of the field of aerodynamics. At one time, people relied only on the observations of how birds flew to develop an understanding of aerodynamics. Once the conservation laws were understood and applied to compressible gases, then the modern understanding of aerodynamics was born. Of course, aerodynamics is now at the level of prediction as manifested by the ease by which aircraft can be designed that fly well. Now, generally speaking, the issues with modern commercial aircraft are not aerodynamics but issues of manufacturing and lifecycle cost efficiency.

The current state of *engineering systems* as defined above is somewhere between levels two (classification) and four (quantification and measurement). Some of the systems have been abstracted, measured and quantified. As with the development of any engineering field, the goal is to move up the hierarchy of knowledge to the point where the behavior of these complex systems can be predicted. Then, it will be the case that when society builds complex engineering systems, it will do so with a good understanding of the likely benefits, costs and consequences of constructing the systems. This will allow these systems to be built on cost, schedule and with the desired performance by individuals with a holistic perspective.

3.5 Future of Engineering Systems

In order for *engineering systems* to move to level seven (prediction) in the hierarchy of knowledge the intersection of the underlying four disciplines will have to be reduced to mathematics or at least computer simulation applicable to many different types of engineering system. This will be greatly aided by two things. These are the discovery of a small number of generalizable, quantifiable principles that go beyond the level of heuristics and the development of a small number of methods that can be applied to many types of engineering systems. The principles will be akin to the conservation laws in fluid mechanics while the methods will be quantified in computer simulations to model these complex systems.

Once these principles and methods are understood, engineering systems will be architected and designed taking into account future partially unknown requirements and uses. Long term uses incorporated through the "ilities" will be designed into the systems in predictive ways. Thus systems will be designed that can be shown to have embedded properties such as safety and security. Systems will be designed with issues of sustainability and flexibility embedded in the original formulation of the system and it will be possible to predict quantitatively the extent to which these properties are present. The full realization of all of these desirable properties of large scale complex systems will come about from bringing together economics, game theory, complexity theory, graph theory, real options theory, and others, along with systems architecture and multidisciplinary optimization. These must be combined with powerful computer simulations in order to model and predict these systems.

A deep question is whether the inclusion of the human dimension of *engineering systems* can ever be fully included in the quantitative prediction of engineering systems. Certainly traditional decision analysis and game theory allows many aspects of human choices to be included but these methods have well known limitations. System Dynamics allows the feedback loops in many systems to be seen clearly while in principle, agent based models allow for large scale simulations from an elemental level. Whether or not, these methods will ever get to include all the interesting intersections of human activities and technical systems is still very open to question.

When *engineering systems* has been fully developed as a field, we predict two major consequences. First, in engineering schools across the world, undergraduates will be educated in the fundamental engineering sciences as now but will also be given an appreciation of the engineering systems context in which some of them will be doing their engineering. At the graduate level, there will be well developed masters and doctoral degrees in the various aspects of engineering systems. Secondly, the development of the field of *engineering systems* will be used to predict the development of new types and next generations of engineering systems. For example, as discussed the National Missile Defense system is clearly a complex type of engineering system and as it evolves over time, we hope the techniques of engineering systems will be brought to bear to predict how it should be designed and how it should behave.

4.0 Case for Positioning Systems Engineering as a Field within Engineering Systems

Given our understanding of *engineering systems* and *systems engineering*, we can now consider the interrelationship of these two fields. We propose the field of systems engineering as an embedded field within *engineering systems*. Over the years, *systems engineering* has suffered from an identity crisis in the sense that it has never quite fit as an engineering science, nor has it quite fit as a management science. This ambiguity has resulted in organizations being unsure of where its practitioners should be placed within the overall organizational structure, particularly in domains outside aerospace and defense. Similarly, in universities we have evidenced schools, divisions, or colleges often reluctant to serve as the host for *systems engineering* departments or programs, citing a lack of academic rigor. The field of *engineering systems* provides an intellectual home for the field of *systems engineering*, as a hybrid engineering-management-policy science into which it can more logically fit. While it may be some time before the emerging field of *engineering systems* influences the organizational structures in corporations, we may sooner see changes to educational institutions in this regard, as exemplified by MIT's Engineering Systems Division which we discuss as one of several new models for systems education.

A secondary effect of this placement can, perhaps, end the debate on the defined scope of *systems engineering*. Taking the classical view, it clearly fits within the overall *engineering systems* field. The expanded view of *systems engineering* includes for example systems architecting and engineering project management, which the classical view assumes as separate. This expanded field approaches equivalence with *engineering systems*, but does not fill the same footprint in its entirety. For example, *engineering systems* includes the enterprise as an essential part of the overall system, while *systems engineering* views enterprise as a consideration or major influence on the (product) system. Engineering systems includes additional subfields that are not contained within systems engineering today. We are now seeing the definition and formulation of *complex systems engineering* (or *system of systems engineering)*, unique from traditional systems engineering but again not a replacement for it. The field of *engineering systems* sits another level above this, by bringing in additional subfields and involves the enterprise as an integral part of the overall engineered system.

3.1 Understanding the Unique Perspectives

The perspectives of each are useful in distinguishing the field of *engineering systems* from its subfield of *systems engineering*. In any large scale systems endeavor, there are instances where one perspective or another is better applied to the challenge at hand. For example, the time to consider changes to the safety policies influencing a system design is optimally in concept development. While in detailed design phase, we would best consider the safety policy as a constraint to the design and manufacture, with its associated operational testing. Some key differences in the individual perspectives are illustrated in Table 1.

Table 1. Systems Engineering Perspective versus Engineering Systems Perspective

	Systems Engineering Perspective	***Engineering Systems Perspective***
Scope	May be applied to small scale to large scale efforts including subsystems, systems, system of systems	Applies to very large-scale, complex open systems which are technologically enabled and have extensive social implications
Policy	Policies and standards are viewed as fixed and a constraint in the system solution	Policies and standards are viewed as variables (at appropriate points in lifecycle) that can be created or adapted to optimize overall system solution
Socio-technical	Socio-technical aspects of the system are viewed as considerations in engineering	Socio-technical aspects of the system are viewed as primary in an overall system solution
Stakeholders	Primary focus on the customer and the end-users of the product system	Balanced focus on all stakeholders impacted by engineering system including product system, enterprise system, environment
Engineering Processes	Architecting, design, and development is applied to the product system	Architecting, design, and development is applied to both the product system and the associated enterprise system
Practitioners	Practitioners are systems architects, systems engineers, and related specialists performing systems engineering process	Practitioners include systems architects, enterprise architects, systems engineers, operations analysis, project managers, policy makers, social scientists, and many more involved in total engineering system
Future Vision	Predictably develop systems with optimal performance for value to satisfy primary stakeholders	Predictably develop evolvable, sustainable engineering systems with optimal value to society as a whole

The authors argue that positioning *systems engineering* within the field of *engineering systems* can also serve to bring about a convergence in the definition of the former, and clarify its boundaries and interfaces. Further, *engineering systems* will influence *systems engineering* in a very positive way in making it a more robust approach, with increased focus on socio-technical issues, the enterprise producing the end system, and overall system properties. Both are evolving fields, and we assert that they must be evolved synergistically. The negative scenario is that if we fail to do so, they will compete with one another and result in increasing the ambiguity about the respective fields.

Engineering systems, because of its very broad nature, has a risk of being viewed as so broad that it has nothing practical to say about real systems. For the field to directly contribute to real-world systems challenges, it must include the practical applied methods needed to create and sustain large-scale complex systems and enterprises. The inclusion of *systems engineering* as one of its essential sub-fields provides principles and proven methods to serve as the essential applied engineering activity. Its practices and activities will also be influenced by engineering systems thinking. Engineering systems, in turn, may introduce new inputs or demands on classical systems engineering practices. The engineering systems perspective may put more focus on environmental requirements; drive more studies on human-systems interrelationship; widen the parameters to be considered in robust design; and have many other influences.

Over forty years ago, Arthur D. Hall (1962) identified five traits of the ideal systems engineer and these certainly still stand today; these traits are: (1) an affinity for the systems point of view, (2) faculty of judgment, (3) creativity, (4) facility in human relations, and (5) a gift for expression. The specific role of the systems engineer has traditionally been rather inwardly focused, with less consideration to environment and external systems. In this broader field of *engineering systems*, the systems engineering practitioners may need to re-evaluate their roles and responsibilities in the overall systems effort, and their relationship to a broader set of stakeholders.

Additionally, these practitioners may find that they need new knowledge to function in this broader context, and that they may require an expanded vocabulary and set of practices in order to collaborate with specialists they have not typically been involved with. For example, as the product system becomes increasing complex and intertwined with environment and enterprise system, systems engineers may find themselves working side by side with a public policy maker or an environmental scientist. This collaboration may already be happening today in certain types of systems efforts such as large public works projects, but it has not been typical for some of the heritage aerospace systems engineers, for example. The result is that it is likely that systems leaders will need to expand both knowledge and viewpoint, and as a result more robust education and practice will be required.

Systems engineering can evolve without the context field of *engineering systems*, but will likely encounter limits that will result in the inability to address the most complex systems challenges of this century. *Engineering systems*, if evolved independently of *systems engineering*, will risk becoming only a theoretic field of the academic realm and limit its ability to contribute to the real engineering problems of society. Their co-evolution will be of mutual and synergistic value to the stakeholders of each of these fields, as well as their related fields.

3.2 Strategies for Evolution

Our vision is for an intellectual positioning of *systems engineering* as an evolving and thriving field within the emerging field of *engineering systems*. We highlight three essential strategies for the realization of our 'field within a field' vision.

Strategy One: *Systems Engineering principles and practices need to be adapted and expanded to fully support the engineering of highly complex systems.*

The principles and practices today which are at the core of *systems engineering* are sound and widely accepted. We assert, however, that these current principles and practices are too limited to deal with all of the issues that we see in large-scale complex systems, as exemplified in (Hughes, 1998). There needs to be additional research and practice to determine how to best adapt and build on these proven practices to accommodate increased complexity (for example, in context of system-of-systems endeavors). Some of the important questions to be considered include:

1. What systems engineering principles and practices are too limited at present to effectively deal with large-scale complex systems with socio-technical interfaces?
2. How can these be adapted and expanded to take the more robust view of the field of *engineering systems*?
3. What new methodologies and tools are needed to implement an expanded set of systems principles and practices?
4. What case studies can show the positive/negative impacts of taking/not taking the engineering systems perspective in designing, developing and sustaining complex systems?

There are many other areas of inquiry related to broadening the systems engineering approach. As an example, research is needed to determine how systems architecting can be adapted for architecting the enterprises that are part of the overall engineering system. MIT and many other leading universities have already initiated research projects to address this question.

Strategy Two: ***Engineering Systems and Systems Engineering are both evolving fields… it is critical that they evolve synergistically and not as two distinct 'competing' fields.***

Systems engineering is not a new discipline, yet it is undergoing significant evolution driven by the increasing technological complexity, globalization, information age, and new systems paradigms such as network-centricity, spiral approaches, and model-based development. *Engineering systems* is an emergent field, and as a meta-level field it is faced with accommodating evolution within its sub-fields, as well as the larger holistic field. This challenge involves a continuous need to harmonize the practices of the subfields as they evolve, and in the process hopefully bring a convergence in definitions and perspectives. Some of the questions to be considered include:

1. How can the varied definitions and views of *systems engineering* converge within the context of *engineering systems* so that a comprehensive approach to systems development is consistently taken?
2. What is the common taxonomy that will serve the needs of *engineering systems* and *systems engineering*, as well as the other subfields of *engineering systems*?
3. What other sub-fields of *engineering systems* are highly interrelated to *systems engineering*, and what research is needed to explore convergence or cooperation of these sub-fields?
4. What lifecycles, practices and methods, when harmonized or adapted, can result in an emergent approach that can better serve the needs of the whole engineering system (product system, enterprise system, and environment)?

Strategy Three: ***Evolving these fields requires changes in systems education strategies, policies, and structures.***

The number of *systems engineering* degree and non-degree programs has been rapidly growing in recent years. In the early 1980s, according to a study cited by (Gasparski 1982), there were 22 Masters and PhD programs in systems studies in universities in the United States. According to an ongoing study by INCOSE, in 2003 there were 94 Masters and PhD programs in the US related to *systems engineering* (Fabrycky, 2003). Although we cite solely the figures for the US, this growth in programs is a trend that is international. These programs are firmly embedded in many universities today, and the structure varies from standalone departments to cross-departmental programs. Curriculum varies, with each university having a specific positioning to offer. Additionally, there are a number of short courses and certificate programs. The core systems engineering fundamentals have experienced some convergence with collaboration through professional societies and consortiums, and can be expected to increase in the coming years. As *engineering systems* continues to evolve, these existing *systems engineering* programs will need to respond in some way. To start we must understand the underlying foundations and implications for educating new systems leaders. An important line of current research focuses on gaining a data-driven foundation for how systems thinking evolves in engineers (Davidz, et al, 2005), and what distinguishes "engineering systems thinking" from the more generalized "systems thinking" (Frank, 2000). Some of the questions to be considered regarding the future of educational policies, structures, and practices include:

1. What new knowledge, skills, and abilities will the diverse set of systems practitioners need for a more robust engineering systems perspective?
2. How will existing curricula need to change if they embrace *engineering systems* as the context field[4]?
3. How will universities need to evolve their structures and policies to support this vision, and what impact will this have on the students of such programs?
4. What kinds for research centers will be associated with such programs and who will be the source of research funding for these highly complex research endeavor?
5. What strategy can be used to transition the current educational model(s) to a new model with *systems engineering* field within context of the *engineering systems* field?

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1. [4] Context drives emphasis, as for example where the issues emphasized in rocket propulsion are different when it is embedded in space system engineering as compared to missile engineering.

6. Does the *engineering systems* context field enable the development of better systems leadership for addressing 21st century engineering challenges?

We believe a new kind of engineering professional is needed in the 21st century and new types of university programs will be needed. We next discuss our vision for this new engineering professional and MIT's efforts to transform engineering education to support this vision.

4.0 A New Kind of Engineering Professional

As this broader understanding of *engineering systems* is developed, a new kind of professional will emerge. These professionals will be powerful integrative leaders that the engineering educational system needs to produce to address the challenges of large-scale complex engineering systems. These leaders will thus be professionals who consider the technological components as part of a larger engineering system (which includes the enterprise) and utilize different approaches than those based on the traditional engineering science paradigm. Engineering systems professionals will also consider the context in which the system operates as a design *variable* rather than a constraint. Thus, they are concerned with the design of the organization that has to manufacture the system or product; the regulations and public policies governing its use and disposition; the marketing; and the relationship with suppliers, distributors and other participants in the value chain. From this perspective, the design process includes the physical attributes that are the domain of traditional engineering; the process attributes, that are the domain of both engineers and managers; and the context attributes that traditionally have been the domain of managers, governments, and social scientists.

These leaders are necessary in society and in the academy to develop an interdisciplinary approach to engineering systems problems that considers the context in which the systems are initiated, designed, manufactured, constructed, implemented, and maintained. That context is undergoing significant change as a result of globalization, the information revolution (the Internet in particular), and emerging social concerns (sustainability in particular). Contemporary academic leaders are recognizing these advanced challenges for academia, as effectively stated by (Vest, 2000),"*Humankind's advances will depend increasingly on new integrative approaches to complex systems, problems, and structures. Design synthesis and synergy across traditional disciplinary boundaries will be essential elements of both education and research*."

These new engineering systems professionals will be critical in the future development of the academy; we suggest they should be about 20% of the engineering faculty of leading engineering schools. They will help to give engineering students the holistic perspective necessary to be productive engineers who will be leaders in modern society. These engineering students once they become engineers will help to lead society in a manner that is technically competent as well as socially aware. This new kind of engineering systems professor will undertake rigorous integrative work and continue to push the traditional engineering science oriented university departments to think more broadly about the nature of large scale engineering in this century. These engineering systems faculty and the students they produce will help the academy address the issues framed by (Kennedy 1997) in his insightful book *Academic Duty.* In the final chapter, he asked, "*Can the universities really make a difference with respect to the Big Problems facing us?*" His list of challenges ranged from arms proliferation and disarmament to ethical issues in genetic testing and counseling to utilization incentives in health-care systems. These problems are intellectually exciting and analytically demanding. However, they do not come in disciplinary packages. Those who wish to work on them face suspicion in the traditional academy which Kennedy asserts stems partly from the traditional academic disdain for "applied" work and partly from common perceptions of multidisciplinary scholarship as "watered down" or "soft". However, these real and complex problems of large scale require the attention of thoughtful intellectuals. Kennedy asks whether the academy can overcome the resistance of departmental structures to "re-engineer" itself in face of these challenges. We argue that part of the answer to this question lies in educating leaders who can operate at the interface of technology and society, with an integrated vision of engineering systems and with the ability to predict them. These professionals in the academy will help us to overcome the world of "two cultures" as Snow (1993) made famous in the last century. And, the academy is exactly the kind of place where these leaders can thrive and where their students can be educated.

However, it will not be business as usual; an academy divided along narrow disciplinary lines with a disdain for multidisciplinary work will not do this. The academy needs to change the way that it thinks about means and ends, and the very purpose of innovation itself. There is a need to forecast the implications of new and emerging engineering systems, and then to take steps to meet the challenges and opportunities they are likely to pose. The academy needs to strategically position itself if it is to produce the kind of leaders who can help society deal with these challenges. We argue that one of the best places for these leaders to emerge is from a broadened perspective on engineering, for a multidisciplinary perspective will be key for future leaders in emerging systems, as well as for the many other important public issues that bridge the culture gap that we have already described. We argue that the big issues in society, the cultural divide that is created and perpetuated by our educational system focused into the two poles of science and the arts and the accelerating pace of technological change in society demand a change in the academy. They also demand a new kind of societal leader flowing from this new vision for engineering.

As described by Moses (2004), the academy must produce societal leaders who are: (1) skilled intellectually at dealing with the many crucial technological dimensions of our society; (2) have the practical results orientation that is characteristic of engineering professionals; (3) have the courage based on early experience to take on the most difficult systems problems; and (4) have the leadership skills to bring others forward as they themselves progress. By doing so, they will help ameliorate the societal response to the technologically driven changes that keep driving and transforming society. Apart from this transformation in the academy to focus on the kind of interdisciplinary work to produce these people, the status quo will prevail and we will not move forward to prediction and improvement of engineering systems for the betterment of society. Many leading universities have begun a transformation to respond to the need for new engineering systems leadership. MIT's Engineering Systems Division is one example of such a transformation and has now had a six year history; in the next section we highlight our program and current challenges faced.

4.1 A New Education Model at MIT

At the Massachusetts Institute of Technology a new educational model and organization for engineering education has been established to address these large-scale engineering challenges of the 21st century, as the Engineering Systems Division (ESD)[5]. The motivation behind ESD is described by founding director Professor Daniel Roos, "A*s you look at what's happening in society, you see technology taking a more important role in our lives, and the systems and products that we use are much more complex. There is a great concern for not only the use of a particular product but the impact of that product or system on people and on the natural environment. This suggests that the role of the engineer is changing significantly, particularly as engineers assume leadership positions. In addition to technical expertise, engineers need an understanding of the broader implications of their profession and the work that they do. That's really the motivation for the Division - it's dealing with complex products and systems. We believe we are defining engineering systems as a new field of study, broadening engineering education and practice". (Roos, 1999)*

MIT's ESD seeks to create and share interdisciplinary knowledge about complex engineering systems through initiatives in education, research, and industry partnerships. ESD takes a broad perspective and enriches engineering practice to include the context of systems challenges as well as the consequences of technological advancement. The division has a dual mission: (1) to define and evolve engineering systems as a new field of study; and (2) to embed this understanding in engineering education and practice. It serves as the intellectual home for key programs and centers, engages faculty across many departments and disciplines, facilitating new dialogues about engineering innovation. ESD brings

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[5] For more information, refer to Engineering Systems Division website at http://esd.mit.edu

together a number of pre-existing academic programs[6] and has added a masters level and doctoral level degree in Engineering Systems, totaling over 400 graduate students. Under the umbrella of ESD, there are four research centers[7] with an annual research volume of nearly $20M. ESD has influenced the collaboration of the various departments and programs within these research centers. The development of ESD *system studies* is a key focus, involving interdisciplinary exercises for teaching engineering systems. They combine traditional "case study" methods with technical models and data sets to teach students how to analyze and develop solutions for complex engineering systems.

The ESD organization includes faculty holding dual appointments that commit their time and efforts to both an academic department and to the division. These dual appointments support the development of new interdisciplinary frameworks and methodologies that define Engineering Systems as a field of study while faculty remain involved with their engineering, management, or social science departments. ESD presently has over 50 faculty and teaching staff from seven engineering departments, and MIT Sloan School of Management and MIT's School of Science and School of Humanities, Arts, and Social Sciences. ESD is developing new intellectual infrastructures as well, including the Engineering Systems Learning Center which serves as a repository and enabler for cases, simulators, and other educational material on complex systems. The Engineering Systems Knowledge Network engages peer institutions, such as Cambridge University and the Technical University of Delft, as partners. ESD is also building on established strengths in policy issues and expanding productive relationships with both industry and government.

ESD has been operating for almost seven years as of the writing of the paper and a comprehensive review of progress and results is underway. The fundamental open question for an academic institution like MIT is whether this model of organizing the faculty will bring added value to the intellectual study of complex systems. The MIT Engineering Systems Division is one example of how universities are striving to change to address the modern complex engineering challenges. It is important that the systems community evolves new models for engineering education, and shares its experiences with these alternative approaches. An informal collaboration of leading universities has recently emerged which is serving to increase the dialogue on how this broader field must evolve and how universities can respond to these challenges for a new type of engineering professional. This is an important dialogue, which INCOSE and other professional societies are also fostering across a broad community of industry, governments, and academia. There is an urgent need to continue such dialogue, to share approaches as well as resources, and to evolve successful models for developing tomorrow's systems leaders.

5.0 Summary

The authors propose that the field of *systems engineering* will most effectively evolve if it is **intellectually positioned** as one of the essential sub-fields within the broader field of *engineering systems*. We believe that "classical" *systems engineering* is not well suited to dealing with the global and socio-technical aspects of the 21st century engineering systems, and it does not adequately address the enterprise subsystem in the overall system. The move to expand *systems engineering* to a much broader field seeks to solve these inadequacies but entirely fill the footprint of the intellectual field needed to address modern systems challenges. The evolution of *complex systems engineering* will provide the approach and methods for system of systems, but still is not entirely sufficient to address the full set of large scale systems challenges. We argue that these fields must evolve, but with it there must also be the

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[6] Degrees offered under programs that preceded ESD, include Leaders for Manufacturing (LFM), System Design and Management (SDM), Master of Engineering in Logistics (MLOG) and Technology and Policy Program (TPP).

[7] MIT ESD research centers include; the Center for Transportation and Logistics; Industrial Performance Center; Center for Innovation in Product Development; and Center for Technology, Policy, and Industrial Development. The latter includes the MIT research center for the Lean Aerospace Initiative, which has significant research in systems engineering and product development.

development and evolution of the larger context field, *engineering systems*, which serves an intellectual purpose that is intertwined with but unique from *systems engineering. Engineering systems* is an emerging field that is enriched by directly embracing the principles, practices, and methods of *systems engineering*, and extending and adapting these, in collaboration with other subfields, to accommodate an even broader purpose. This can be viewed by using the system-of-systems paradigm, wherein the field of *engineering systems* provides a unique intellectual contribution, beyond that that is provided by the pure summation of the intellectual contribution of its component subfields, which simultaneously continue to exist as unique intellectual fields of their own.

Two decades ago, Booton and Ramo (1984) noted the trend in increasing complexity of complex systems and that "*we should anticipate the use of systems engineering techniques on an even wider range of systems than in the past*". These authors also asserted "*the need for a systems approach to major problems of society*" and that "*the fundamental concepts of systems engineering, even if not all of its specific tools, would improve handling of such problems in the future*". In these comments, we see the authors beginning to reach for this broader field.

We believe that placing *systems engineering* within the context field of *engineering systems* will further enable its evolution to more effectively contribute to addressing the engineering challenges of this century. Further, the educational system must undergo significant change to develop the new integrative engineering systems leadership which will include transformations in the existing systems engineering university programs. *Engineering systems* and *systems engineering* are both rapidly evolving fields, and we believe it is critical that they evolve synergistically and not as two distinct 'competing' fields. Systems engineering educational programs have increased significantly in the past two decades, and if *engineering systems* provides an intellectual context field, there must be major transitions in engineering education strategies, policies, and structures. We have highlighted MIT's Engineering Systems Division as one new model for this new approach.

In 1971, Lunar Module Commander Apollo 14, Edgar D. Mitchell, stated "*…the solution lies in the direction of taking a systems view of things. When you have the view from space, you realize that the concept of fields within fields within fields, systems of functioning within systems of functioning, is the only approach that will work."* Our view is that systems engineering is a field that is embedded within a larger field of engineering systems. The complex societal-engineering challenges of this century can only be addressed when this "fields within fields" perspective, is effectively applied to developing these new systems leaders.

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[8] The monograph series of the MIT Engineering Systems Symposium is published online at http://esd.mit.edu/symposium/monograph

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