Confronting an identity crisis – How to 'brand' Systems Engineering

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Abstract

Systems Engineering is not a new discipline; the term has been in use since World War II. Yet, whilst there has been no shortage of definitions of the term over the years (not all of which are consistent), there is little consensus on the scope of Systems Engineering. This is particularly true in relation to other overlapping disciplines such as System Dynamics, Operations Research, Industrial Engineering, Project Management, Soft Systems Methodology, Specialist Engineering and Control Theory, which share many of the origins and techniques of Systems Engineering. This paper presents a landscape of disciplines and suggests that INCOSE should 'brand' Systems Engineering strategically, defining explicitly its position within this landscape including its points of parity (overlaps) and points of difference with other disciplines. Actively branding Systems Engineering will broaden its appeal and attract more interest from stakeholders outside the current Systems Engineering community. INCOSE's 'market share' relative to its biggest systems competitor – Project Management – is falling, so even though INCOSE membership is rising, more needs to be done to promote the profession.

Key words: scope of systems engineering; branding systems engineering; selling systems engineering; landscape of systems disciplines; history of systems disciplines

1 Introduction

Despite being more than sixty years old, Systems Engineering (SE) still doesn't know very well what it is. When systems engineers look in the mirror, what do they see? They see furtive creatures, no doubt, with features that are difficult to make out with any constancy. They see shape-shifters, perhaps, as each day they have different roles and see themselves in a different light. Worse still, external observers see only shadows. Whilst the SE community may be occasionally confused over its purpose, there can be little doubt that those outside this community would be in a state of perpetual perplexity over the activities of systems engineers. Would be, that is, if they were the least bit interested in us.

If SE is to develop into anything more than an engineering niche, it needs to be branded, so that those outside the community are forced to sit up and take notice. In order to create a brand identity for SE, though, we need better agreement within the SE community over who we are and what we want to be. Shape-shifters just aren't selling at the moment. INCOSE is still quite young and has made positive strategic moves in the last few years, but it may need to be even more aggressive if it is to get discussions about SE out of the lab and into the boardroom. The concept of treating a profession as a brand has precedents. For example, the market research profession, which has some similarities to SE in the way that it combines quantitative analysis with creative recommendations, has had a lively debate in the last decade about how to market itself. This has gone as far as considering "ditching the Market Research name altogether" [Valentine, 2002].

We begin the search for a way to brand or market SE with a degree of introspection. It will be useful to start with a brief discussion of the scope and history of SE, and then to identify other 'overlapping' fields of study. We will then be in a position to discuss the 'unique selling propositions' of SE and of systems engineers. This should uncover what functions the discipline of SE should perform that other disciplines do not or cannot perform, and what competencies are required of an individual who is to perform these functions. We then consider who takes responsibility for setting the scope of SE and who the stakeholders of SE are before concluding with a discussion of how SE should brand itself within the landscape of overlapping disciplines and how it can go about doing this.

2 The scope of Systems Engineering

A newcomer to the field of SE could be puzzled by the scope of the subject given how many other apparently similar subjects exist with the words ‘System’, ‘Systems’ or ‘Engineering’ in their titles. A glance around the shelves of the British Library would do little to clarify matters, merely uncovering a wealth of journals with apparently overlapping scope. There seem to be countless societies dedicated to the promotion of ‘Systems’ and ‘Engineering’, each with its own journal, web page and conferences.

Textbooks aren’t much help, either. Some see SE as part of Project Management [Kossiakoff and Sweet, 2003]. Some see Soft Systems Thinking as part of SE, others draw the distinction between hard SE and Soft Systems Methodology (such as Khisty and Mohammadi [2001]). Some texts stress the importance of economics in general engineering [Crandall and Seabloom, 1970], and many SE texts underline cost-benefit trade-offs as critical to good SE. One of the earliest recognised practitioners of modern-day SE, Arthur Hall, suggests “Systems engineering operates in the space between research and business, and assumes the attitudes of both. For those projects which it finds most worthwhile for development, it formulates the operational, performance and economic objectives, and the broad technical plan to be followed” [Checkland, 1981:130]. Prior to the 1960s, it was common to treat technology and cost as independent considerations in developing military systems. However, Hitch and McKean [1960: 3] point out that “Technology defines the *possible* strategies. The economic problem is to choose that strategy, including equipment and everything else necessary to implement it, which is most efficient (maximizes the attainment of the objective with the given resources) or economical (minimizes the cost of achieving the given objective) – the strategy which is the most efficient also being the most economical”.

A number of questions are answered inconsistently in the literature. These include whether SE can be applied to non-engineering systems. In other words, is SE about engineering in the general sense of ‘to engineer’ - i.e. to make something happen in a clever way, or is the engineering referring to the traditional engineering profession which focuses on scientific problems? SE has an “international professional society for systems engineers whose mission is to foster the definition, understanding, and practice of world class systems engineering in industry, academia, and government” [INCOSE, 2004a] – namely the International Council on Systems Engineering (INCOSE). It would be appropriate to refer to the INCOSE definition of SE: “Systems Engineering is an interdisciplinary approach and means to enable the realization of successful systems. It focuses on defining customer needs and required functionality early in the development cycle, documenting requirements, then proceeding with design synthesis and system validation while considering the complete problem: Operations, Performance, Test, Manufacturing, Cost & Schedule, Training & Support, Disposal. Systems Engineering integrates all the disciplines and specialty groups into a team effort forming a structured development process that proceeds from concept to production to operation. Systems Engineering considers both the business and the technical needs of all customers with the goal of providing a quality product that meets the user needs” [INCOSE, 2004b]. It is interesting to note that the INCOSE definition includes no description of what is meant by a system and has no reference to engineering; it also makes no assumption that SE is relevant only to machines or technical systems. INCOSE should therefore consider soft systems analysis as within the scope of SE.

In contrast, the Oxford English Dictionary (OED) defines Systems Engineering as: “the investigation of complex, man-made systems in relation to the apparatus that is or might be involved in them; so systems engineer” [Simpson and Weiner, 1989]. This definition is more restrictive than the one used by INCOSE, limiting attention to man-made systems, and underlining the importance of ‘the apparatus that … might be involved in them’ – suggesting a focus on physical machines rather than systems in a general sense (the OED defines apparatus as “…equipments, material, mechanism, machinery; material appendages or arrangements…” [Simpson and Weiner, 1989]).

Optner [1975] proposes a rather confusing definition: “In parallel with the emerging interest in engineering systems, there was equally vital activity in the field of information systems. Where engineering systems were identified with equipment (now widely referred to as “hardware”), information systems were concerned with the origins, processing, and meaning to be inferred from data. The integration of hardware components into complex electronic or electromechanical end-products came to be known as systems engineering”. Perhaps the association between systems and computers has existed since the introduction of general systems theory, which predates SE: “Systems theory … is pre-eminently a mathematical field, offering partly novel and highly sophisticated techniques, closely linked with computer science” [Bertalanffy, 1968: xi]. The confusion surrounding SE in general and Information Systems Engineering still remains today. In 1996, the UK Engineering and Physical Sciences

Research Council, which funds research in UK Universities, set up a research programme to investigate the relationships between legacy IT systems and business processes. The research programme was called “Systems Engineering for Business Process Change” [Henderson, 2002]. This is a clear and typical example of when ‘Systems Engineering’ is used to refer to ‘Information Systems’ or ‘Computer Systems’.

Some attempts to understand the scope of ‘Systems Engineering’ begin by decomposing the term into its constituent parts, understanding each part independently and then trying to knit the two together to understand the whole. Of course, it is entirely appropriate and not without irony that this reductionist approach to understanding the meaning of ‘Systems Engineering’ is a fruitless task. The situation is worsened by the fact that there seems to be so little agreement about what the words ‘system’ and ‘engineering’ actually mean.

Goode and Machol [1957] identify a problem of definition that still seems to blight the profession today: “for more than a decade, engineers and administrators have witnessed the emergence of a broadening approach to the problem of designing equipment. This phenomenon has been poorly understood and loosely described. It has been called system design, system analysis, and often the systems approach. Rarely does the speaker using these terms intend to convey those concepts which are brought to the minds of his hearers, nor for that matter are two hearers likely to be in agreement”. The fact that there is so little understanding of the meaning and scope of these terms nearly fifty years after the problem was originally identified does not reflect well on the systems engineering ‘profession’. Indeed whether it is possible to be a ‘professional’ systems engineer is debatable. Pettee [1954] notes that “many of the descriptions convey a feeling that a ‘pro’ in this business is a jack of all trades and a master of none” and, if this were so, “this would not, of course, be a profession”. Though Pettee was actually referring to an operations researcher, he could easily have been referring to a systems engineer.

Starting from a rather loose definition of a system, namely ‘any grouping of resources with a definite objective’, Jenkins and Youle [1971] provide one of the first definitions of SE to stress the importance of emergence: “Systems engineering is the science of designing complex systems … so that the individual parts (or sub-systems) making up the overall system can be designed, fitted together, checked and operated so as to achieve the overall objective in the most efficient way. Thus, systems engineering replaces a piecemeal approach to problem solving in organizations by a disciplined, overall approach. An overall approach is necessary because many problems which arise in industry are associated not with a particular function in a company, but with interactions between people, functions and departments"

Rechtin [1991: 13] contributes to the debate on the meaning of SE by distinguishing between 'systems engineering' and 'systems architecting', suggesting that the architect is "not a 'general engineer', but a specialist in reducing complexity, uncertainty, and ambiguity to workable concepts". He describes a systems engineer, in contrast, as "the master of making feasible concepts work". Rechtin [2000: 5] elaborates by suggesting that architecting is "generally synthesis-based, insightful, inductive" whilst engineering is "analysis-based, factual, logical, and deductive". These definitions do not make clear where value for money analyses should be considered. Since these should be driven by market data you could argue that they are factual, logical and deductive, and therefore should fall under engineering. But Rechtin states that it is the architect's job to "determine relative requirement priorities, acceptable performance, cost and schedule – taking into account such factors as technology risk, projected market size, likely competitive moves, economic trends, …" [Rechtin, 1991: 13]. Furthermore, Maier and Rechtin state that "engineering is more of a science, architecting more of an art" [Maier and Rechtin, 2000]. Surely few with the responsibility of 'architecting' complex technical systems would describe themselves primarily as artists. The distinction between systems engineers and systems architects therefore seems a little hazy. Nevertheless, some organizations must find this distinction useful, as INCOSE set up a Systems Architecting Working Group and the IEEE has a Software Engineering Standards Committee's Architecture Working Group [Maier and Rechtin, 2000].

A further twist has been introduced by MIT, who recently hosted an 'Engineering Systems' symposium. Engineering systems is defined as "an evolution of the systems approach that addresses the challenges imposed by the size, scope and complexity of modern organizations and their technical solutions" [Wolff, 2004]. This is claimed to be not just systems engineering, but "enterprise engineering", or "systems engineering applied to a large organization". Given the confusion concerning the scope of systems engineering, reversing the words seems unlikely to help, particularly since it is clear that engineering systems involves the same kind of approach as systems engineering. If there is a valid distinction between engineering systems and SE, it is hard to see how engineering systems is also conceptually distinct from Operations Research, defined in Section 3.1 below as "a scientific approach to the solution of problems in the management of complex systems”. The geneses of the terms ‘engineering systems’ and ‘systems architecting’ are symptoms of the failure of SE to mark out its territory in the systems landscape. With SE narrowly defined, it seems reasonable that ‘engineering systems’ and ‘systems architecting’ could be seen as completely distinct from SE. However, a broader view of SE would see engineering systems and systems architecting as just special cases or subsets of SE. There therefore needs to be clarification of whether these fields are subsets of SE, overlapping disciplines or distinct disciplines.

The difficulties with defining the scope of SE may be linked to its origins and history. SE principles have been applied as far back as for the building of the pyramids, and the Bible suggests that Noah’s Ark was built to a system specification (Genesis 6: 13-22). The emergence of SE as a distinct discipline is usually associated with the management of technological projects during and after World War II, though. Indeed, it wasn’t until the 1950s and 1960s that the first textbooks emerged that referred to SE by name (such as Goode and Machol [1957]). Traditionally, SE arose out of a recognised need to engineer functional systems that spanned different disciplines of engineering. With the early projects primarily military and space based (see Westerman [2001]), SE was established as an approach to optimise complex systems with very clearly defined requirements, and with cost considerations of secondary importance. “The modern philosophy – the ‘why’ and the ‘how’ of today’s systems engineering developed largely at NASA in the 1960s and 1970s” [Hitchins, 2003: 76]. The early military/aerospace presentation of systems engineering emphasized the process involved rather than the holistic principles. The Defense Systems Management College produced a *Systems Engineering Management Guide* [DSMC, 1983] which explained the steps in SE, starting with ‘requirements analysis’ and ending in the ‘synthesis’ of alternative solutions.

Jenkins and Youle at Lancaster University had great expectations of the impact of SE which were, with hindsight, misplaced: “it is not unreasonable to claim that a new industrial revolution is now on its way with the advent of systems engineering, a revolution which is going to exert a major influence on how industry can be organized so as to integrate properly the potentialities of people and the possibilities of technology” [Jenkins and Youle, 1971]. SE has always drawn upon expertise from a broad range of disciplines, including in particular mathematics and the physical sciences. However, perhaps fuelled by the Lancaster school’s optimism, SE seems to have become more ambitious in its scope in the last twenty years.

From optimising well defined, ‘hard’ systems with clearly specified requirements, SE is now increasingly being applied to offer insights into poorly defined, ‘soft systems’ with loosely defined requirements. A whole session was dedicated to ‘Soft Systems Approaches’ in the 2001 INCOSE UK Spring Symposium. But is there such a thing as Soft ‘Systems Engineering’? The development of Soft Systems Methodology (SSM) was an attempt to address questions that, by definition, were outside the scope of SE as it was defined at the time [Checkland, 1981]. Yet INCOSE’s definition of SE and proceedings from INCOSE conferences now suggest that INCOSE believes that SSM falls within its scope of operations. This is interesting, since there are many other disciplines on the margins of SE which SE has manifestly declined to take under its wing. Perhaps SE as a discipline needs to examine its similarities and differences to other disciplines so that it can better highlight what the essence of ‘Systems Engineering’ is and what the scope of SE could or should be in the future. The roots of ‘hard’ SE are clear, and the development of SE as a discipline is firmly tied to these roots. But the ‘marketplace’ of systems-related disciplines has changed in the last fifty years, and SE needs to consider carefully whether its current stance and scope are still optimal for the new world order. First we should discuss some of the disciplines which overlap with SE.

3 Overlapping disciplines

As SE emerged during World War II, other similar disciplines were established with similar goals and methods, applying mathematical and scientific rules to real-world problems. These include in particular Operational or Operations Research, which concerns itself with the optimal allocation of resources and Systems Analysis, concerned with applying economics and mathematics to non-engineering problems (although systems analysis now seems increasingly to refer to Information Systems only). In addition, SE overlaps significantly with several newer areas, namely Project Management, System Dynamics and Soft Systems Methodology. For a comprehensive history of the development of SE, Operations Research and Project Management see Johnson [1997].

Even before WWII, the systems idea was gaining momentum, although it wasn’t referred to under its modern day terms. F. W. Taylor, the pioneer of industrial efficiency and specialization of work, noted that “in the past, the man has been first; in the future the system must be first” [Taylor, 1911: 7]. Industrial Engineering was effectively born with the thinking of Taylor as well as Frank and Liliam Gilbreth [Martin-Vega, 2001: 1.5]. It developed with

Ford's assembly lines, Elton Mayo's Hawthorne experiments and later with the motivation theories of Herzberg, Maslow and McGregor into what we would consider modern scientific management [Brown, 1954]. Following WWII, Industrial Engineering, Operations Research and (to a lesser extent) SE began to converge as they attempted to answer similar questions of optimization. The nature of SE's relationship with each of these other fields is discussed below.

3.1 Operations (or Operational) Research

Operations or Operational Research (OR) is a well-established area of study with many associated societies throughout the world. The International Federation of Operational Research Societies (IFORS) defines the field as follows: "OR can be described as a scientific approach to the solution of problems in the management of complex systems … OR has been used intensively in business, industry, and government. Many new analytical methods have evolved, such as mathematical programming, simulation, game theory, queuing theory, networks, decision analysis, multicriteria analysis, etc. which have powerful application to practical problems with the appropriate logical structure" [IFORS, 2004]. IFORS is an international group which represents national research societies around the world (the largest of which is the US-based Institute for Operations Research and Management Science, INFORMS). An older definition from the (UK) OR Society's official definition is: 'OR is the application of the methods of science to complex problems arising in the direction and management of large systems of men, machines, materials and money in industry, business, government, and defence. The distinctive approach is to develop a scientific model of the system, incorporating measurements of factors such as chance and risk, with which to predict and compare the outcomes of alternative decisions, strategies or controls. The purpose is to help management determine its policy and actions scientifically' [Checkland, 1981]. Duckworth offers a similar definition of OR: "the study of administrative systems in the same scientific manner in which systems in physics, chemistry and biology are studied in the natural sciences" [Duckworth, 1965: 8].

There seems to be a strong overlap between the questions that Operational Research seeks to answer and the questions that SE could help to answer if applied to non-engineering projects, since both are systems approaches [Churchman, Ackoff and Arnoff, 1957]. The key difference in emphasis between SE and OR is that SE tends to focus on the development of optimum new or modified systems, whereas OR generally strives to get the best performance out of existing systems. Hall [1962] explains that “operations research is usually concerned with the operation of an existing system, including both men and machines. Thus we find operations research looking at military operations, supermarkets, factories, farms, etc., and examining specific functions within these operations such as inventory control, distribution of raw and finished materials, waiting lines, advertising, etc. The object is usually to optimise or to make better use of materials, energies, people, and machines already in existence and at hand. In contrast, systems engineering emphasizes the planning and design of new systems to better perform existing operations, or to implement operations, functions or services never before performed.” A slightly different emphasis is offered by Goode and Machol: “The operations analyst is primarily interested in making procedural changes, while the system engineer is primarily interested in making equipment changes” [Goode and Machol, 1957: 130].

Nevertheless, there is much common ground between the two disciplines. “Both engage in the analysis of complex man and machine systems … both utilize multi-discipline teams; both employ the scientific method; both emphasize the “whole system” rather than the component approach; and, above all, both are staff elements of organization whose mission is the analysis of operations … The differences are much less important than the similarities…The differences between operations research and systems engineering lie more in the people who do the work than in concept, philosophy, or procedure” [Flagle, Huggins, and Roy, 1960]. However, Flagle, Huggins and Roy also point out that “detractors could not distinguish between systems engineering and operations research but agreed that both lacked substance” and that “some alleged that operations research was nothing but industrial engineering”. Hughes [1998: 9] recalls that “In the 1960s, advocates of the systems approach developed a package of techniques and theory that included not only systems engineering but also systems analysis and operations research. While systems engineering was developed to manage large projects, operations research was designed to analyze military operations in place, and systems analysis was developed to analyze the anticipated costs and benefits of alternative planned projects, especially military ones. Together, these techniques have generated a managerial revolution comparable to that brought about earlier by Taylor’s scientific management”. The commonality between OR and SE is highlighted well by Johnson, who examines the technical content of early textbooks on OR and SE finding “substantial overlap and no universal consensus” [Johnson, 1997: 913]. The core subjects of

OR in the 1950s and 1960s were probability and statistics, linear programming, queuing theory, and game theory. The content of SE texts varied more, with the most significant topics including probability and statistics and control theory.

3.2 Industrial Engineering

Although he didn't use the term 'industrial engineering', F. W. Taylor's writing on efficiency and specialization of work is generally regarded as the foundation of the discipline [Martin-Vega, 2001: 1.5]. OR and Industrial Engineering (IE) shared a common goal – getting the most out of existing systems, such as finding the best way to produce and distribute goods. After the end of WWII, some operations researchers therefore extended their areas of activity to include industrial problems. "This resulted in considerable interaction between industrial engineers and members of other scientific disciplines and in an infusion of new ideas and approaches to problem solving that dramatically impacted the scope of industrial engineering education and practice" [Martin-Vega, 2001: 1.10]. From the 1960s, industrial engineers came to use OR as a tool to model and better understand the behaviour of large problems and systems. Coupled with the development of the digital computer, this "essentially changed industrial engineering from a field primarily concerned with the individual human task performed in a manufacturing setting to a field concerned with improving the performance of human organizations" [Martin-Vega, 2001: 1.11]. The distinction between OR and IE is therefore slight. Hicks [2001: 1.85] points out that "the theoretical basis of industrial engineering is a science of operations … Almost always, the goal of industrial engineering is to ensure that goods and services are being produced or provided at the right quality at the right time at the right cost", which sounds very much like a description of OR applied to a business problem. Yet, Hicks adds that a practising engineer uses 'soft' as well as 'hard' science, and "in the final analysis, the industrial engineer's job is to make both new and existing operations perform well", which blurs the previously drawn distinction between SE and OR (that OR focuses on existing processes). Perhaps, then, the scope of IE overlaps with SE as well as with OR. This view would be supported by Greene, who states that "there have been many suggestions for new terms that would better define industrial engineering. At times, over the last several decades, the terms *systems engineer, management engineer, productivity engineer, quality engineer, and improvement engineer* have been suggested to describe the future and direction of industrial engineering" [Greene, 2001: 1.100]. Furthermore, in an IE handbook published in cooperation with the Institute of Industrial

Engineers [Salvendy, 2001], an 'industrial and systems engineer' is defined as "one who is concerned with the design, installation, and improvement of integrated systems of people, material, information, equipment, and energy by drawing upon specialized knowledge and skills in the mathematical, physical, and social sciences, together with the principles and methods of engineering analysis and design to specify, predict, and evaluate the results to be obtained from such systems" [Sink, Poirier and Smith, 2001: 5]. These authors further present a view of how they see the overlap between the activities of the industrial and systems engineer (ISE) and that of other disciplines (Figure 1).

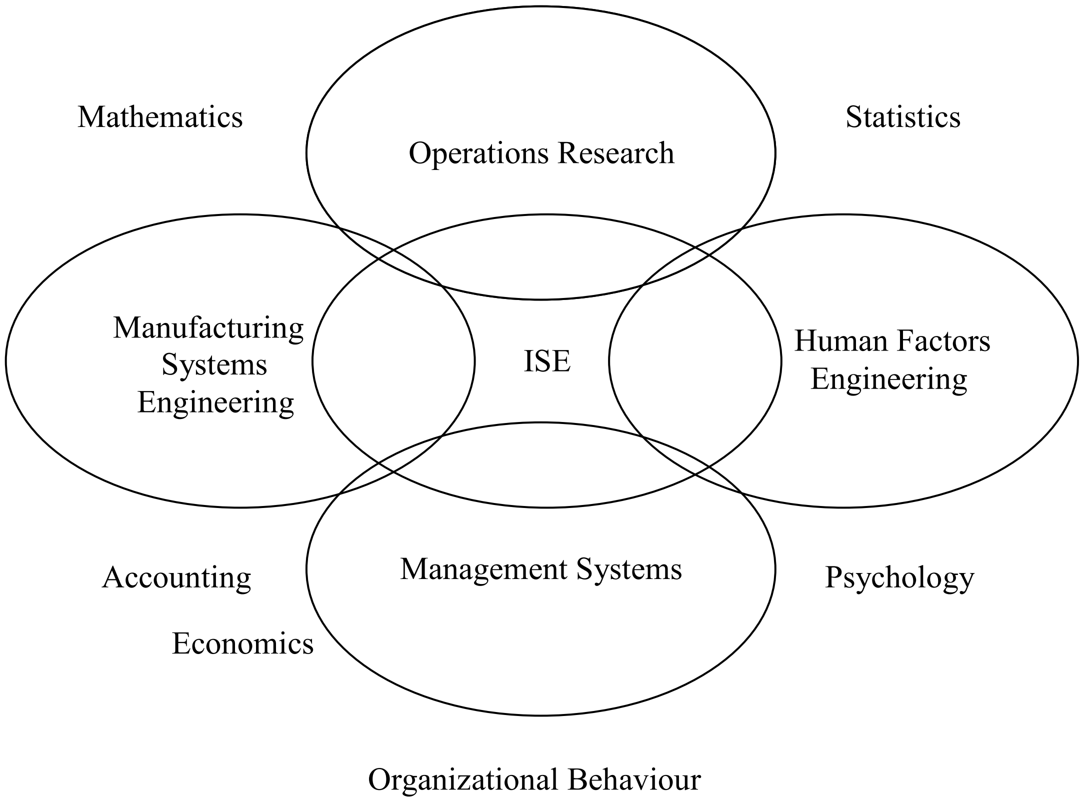


Figure 1: Overlap of ISE activity with other disciplines [Sink, Poirier and Smith, 2001]

Martin-Vega [2001: 1.13] supports the idea that industrial engineers and systems engineers have common skills, feeling that industrial engineers were "uniquely qualified to play the integrative, systems-oriented role that was now required to enhance the effectiveness of organizations". This and the number of combined Systems Engineering and Industrial Engineering departments in US universities suggest a significant synergy between the two fields.

3.3 Systems Analysis

‘Systems Analysis’ was developed in the 50s in the US as a technique for comparing the alternatives facing a decision maker by the RAND Corporation (www.rand.org), a non-profit-making organisation. This was possible because of the involvement of scientifically-trained civilians in the planning of military operations in World War II: “During the 1950s the pattern of RAND-style ‘systems analysis’ became clearer. The work done consisted of broad economic appraisal of all the costs and consequences of various alternative means of meeting a defined end. It was a refinement of the kind of cost-benefit analysis which had been developing in government since the 1930s and of the ‘requirements approach’ especially associated with the Department of Defense” [Checkland, 1981: 135]. Essentially, Systems Analysis was a forward looking extension of Operations Research: “During the war, operations researchers focused on the tactical operations of existing weapons. RAND researchers extended OR techniques to investigate the potential value of future systems, using many of the techniques developed by operations researchers and extending them with best-guess assumptions regarding the future. They called this future-oriented operations research systems analysis” [Johnson, 1997: 898]. ‘Systems Engineering’ and ‘Systems Analysis’ are both methods of ‘hard’ systems thinking, which assume that problems can be structured as a choice between alternative ways of achieving a known objective.

Hitch [1973] describes the elements of systems analysis as:

1. An objective or objectives we desire to accomplish
2. Alternative techniques or instrumentalities (or ‘systems’) by which the objective may be accomplished
3. The ‘costs’ or resources required by each system
4. A mathematical model or models; i.e. the mathematical or logical framework or set of equations showing the interdependence of the objectives, the techniques and instrumentalities, the environment, and the resources
5. A criterion, relating objectives and costs or resources for choosing the preferred or optimal alternative

This approach clearly has much in common with SE.

Checkland [1981: 137] notes that in business and management there is some confusion of 'systems analysis' in the broad , RAND, sense with the more limited kind of computer systems analysis which must precede the installation of computers. Checkland goes on to summarize the overlap between Systems Analysis and SE. "Systems Engineering is the totality of an engineering project in the broadest sense of that term; Systems Analysis is a type of appraisal relevant to both the decision-making which ought to precede the setting up of any engineering project and to the early stages of such a project once it is started" [Checkland, 1981: 138].

Over the years since the inception of Systems Analysis, its scope seems to have drifted. Initially, it referred to formal optimisation of complex problems with known objectives. Over time it became implicit that the analysis *of the systems* would require application of advanced quantitative techniques that were only possible using computers. Systems Analysis therefore came to mean the solution of systems problems using computer systems. Today, the terms 'systems analysis' and 'systems analyst' are mostly used to refer to situations where computer systems are designed to solve problems of a general kind. In other words, the 'systems' in 'Systems Analysis' has changed from referring to the nature of the object of study for which a solution is required (i.e. complex systems), to the nature of the mechanism used to achieve the solution (computer systems). In fact, a general confusion exists between the distinction between information technology, systems, and information systems [Checkland, 1998]. Stoddart also highlights the misconception "that all systems are based on computers and that systems engineering is closely allied to software engineering" [Stoddart, 1999: 129].

3.4 System Dynamics

System Dynamics is a methodology for studying and managing complex feedback systems. "The methodology identifies a problem, develops a dynamic hypothesis explaining the cause of the problem, builds a computer simulation model of the system at the root of the problem, tests the model to be certain that it reproduces the behaviour seen in the real world, devises and tests in the model alternative policies that alleviate the problem, and implements this solution" (System Dynamics Society, 2004). The field developed initially from the work of Jay W. Forrester and his publication of *Industrial Dynamics* [Forrester, 1961]. This focused on "the information-feedback character of industrial systems and the use of models for the design of improved organizational form and guiding policy." *Industrial Dynamics* grew out of four previous lines of development: "information-feedback theory, automatizing military tactical decision making, experimental design of complex systems by the use of models, and digital computers for low-cost computation" [Forrester, 1961]. The origins of System Dynamics are described by Sterman: "System dynamics is grounded in the theory of nonlinear dynamics and feedback control developed in mathematics, physics, and engineering. Because we apply these tools to the behavior of human as well as physical and technical systems, system dynamics draws on cognitive and social psychology, economics, and other social sciences" [Sterman, 2000: 5]. Since the publication of *Industrial Dynamics*, the span of applications has grown extensively and now extends to corporate planning and policy design, public management and policy, biological and medical modelling, energy and the environment, theory development in the natural and social sciences, dynamic decision making, and complex nonlinear dynamics. System Dynamics has been applied in a range of fields including health care (see for example Dangerfield [1999]), defence [Coyle, Exelby and Holt, 1999] and energy [Corben, Stevenson and Wolstenholme, 1999].

Although System Dynamics seems to share some of the heritage and raison d'être of SE, there are now relatively few areas of overlap between the two fields. System Dynamics tends to focus on improving the understanding of existing systems, whilst SE is almost entirely applied to the development of new systems. Furthermore, the 'systems' to which 'System Dynamics' is applied are often business or social systems, whereas SE has traditionally been applied almost exclusively to technical systems. Nevertheless, there are many techniques applied in System Dynamics which might usefully be applied in SE. For example, System Dynamics models have been developed to estimate the repercussions of design changes during major engineering projects. These models have been pivotal in determining the responsibility for project cost overruns and have thereby settled legal disputes [Sterman, 2000: 55-66]. But the real value of System Dynamics models for project managers and systems engineers lies in "using these models proactively so overruns and delays are avoided in the first place" [Sterman, 2000: 65]. There is even greater overlap between research in System Dynamics and research in OR. Lane points out that "at its inception, the paradigm of system dynamics was deliberately made distinct from that of OR. Yet developments in soft OR now have much in common with current system dynamics modelling practice … a dialogue between the two would be mutually rewarding" [Lane, 1994]. Hughes notes how Forrester distinguishes between system dynamics and operations research: "The applier of system dynamics is compared to an airplane designer, while one doing operations research is like an airplane pilot. OR, he continues, is for the decision-making manager, while system dynamics is for the designer of corporate policies. Just as an engineer designs a physical system for desired performance, a manager or political leader can aspire to design policies for social systems" [Hughes, 1998: 176].

3.5 Systems Thinking/Soft Systems Methodology

There are significant areas of common ground between Systems Thinking and System Dynamics: "Systems Thinking looks at exactly the same kind of systems from the same perspective as System Dynamics but rarely takes the additional steps of constructing and testing computer simulation models, and testing alternative policies in the model" [Systems Dynamics Society, 2004]. 'Soft Systems Methodology' first emerged in the public domain [Wilson, 2001] with the publication of Checkland's [1981] 'Systems Thinking, Systems Practice'. Checkland [1981: 318] defines SSM as a "systems-based methodology for tackling real-world problems in which known-to-be-desirable ends cannot be taken as given. Soft systems methodology is based upon a phenomenological stance" (i.e. where human perception and interpretation are taken to influence reality). Jackson [1991] highlights the role of Systems Thinking within the modernism/post-modernism debate: "Post-modernism seeks to puncture the certainties of modernism, particularly the belief in rationality, truth and progress; and it delights in doing so. It denies that science has access to objective truth". Systems Thinking, as a response to the practical limitations of 'hard' SE, is therefore consistent with a post-modernist worldview.

A distinction between systems thinking and systems science is not always drawn, but one 1964 IEEE definition of systems science sees it "embracing operations research, systems analysis, and systems engineering" [Hughes, 1998: 141]. Systems Thinking, on the other hand, tends to focus on 'soft' systems engineering. There has been an International Society for the System Sciences (http://www.isss.org/) since 1954 (established as the Society for General Systems Research) and a UK Systems Society (UKSS) since 1977 [Stowell, 2002]. UKSS is "committed to the development and promotion of 'systems' philosophy, theory, models, concepts and methodologies for improving decision-making and problem-solving for the benefit of organisations and the wider society" [UKSS, 2004]. UKSS stated interests include "understanding human behaviour, general management and specific management (e.g. public sector), approaches to problem solving, information handling and computing, mathematical modelling and optimisation, general problems of technology (e.g. safety and failures), particular problem application areas (e.g. agriculture), biology and medicine, and education" – many of which overlap with INCOSE areas of interest. According to UKSS, "the concept of 'system' embodies the notion of a collection of elements connected together to form a whole. Systems Thinking uses this concept to help understand the world. Central to the approach are the ideas of emergence and hierarchy, and communication and control. Systems practice employs systems ideas to design and manage complex processes and artefacts for the benefit of individuals, organisations and society" [UKSS, 2004].

3.6 Project Management

The term 'project management' emerged in the late 1950s when the "size, scope, duration, and resources required for new projects began to deserve more analysis and attention" [PMI, 2000]. Established in 1969, the Project Management Institute (PMI) is the world's largest project management professional association and provides some useful definitions relating to Project Management: "A project is a temporary endeavour undertaken to achieve a particular aim and to which project management can be applied, regardless of the project's size, budget, or timeline … project management is the application of knowledge, skills, tools, and techniques to a broad range of activities in order to meet the requirements of a particular project" [PMI, 2000]. The PMI Body of Knowledge goes on to describe project management as comprised of five processes: "Initiating, Planning, Executing, Controlling, and Closing" as well as nine knowledge areas, focusing on: "management expertise in Project Integration, Project Scope, Project Time, Project Cost, Project Quality, Project Human Resources, Project Communications, Project Risk Management and Project Procurement". OR makes theoretical contributions to the study of Project Management, but these contributions are often too theoretical and mathematical to be useful in practice. For example, see Schmidt and Grossman [2000] who predict the "exact overall time distribution of a project with uncertain task durations". There is, however, a significant overlap between the activities of project managers and those of systems engineers. Indeed, it has been claimed that "Systems engineering is an inherent part of project management" [Kossiakoff and Sweet, 2003]. Furthermore, projects that deliver systems can be viewed as systems in their own right [Stoddart, 1999].

A project can be defined as "a complex, coherent, interdependent group of activities, which combine to deliver common, novel objectives in a finite duration within a fixed amount of resource … Projects can be viewed as the interaction of three types of abstraction: quality, time and resource" [Cowper and Smith, 2002]. Tension exists between the three abstractions (shown in Figure 2) and Project Management must balance and trade these off to achieve a successful project.

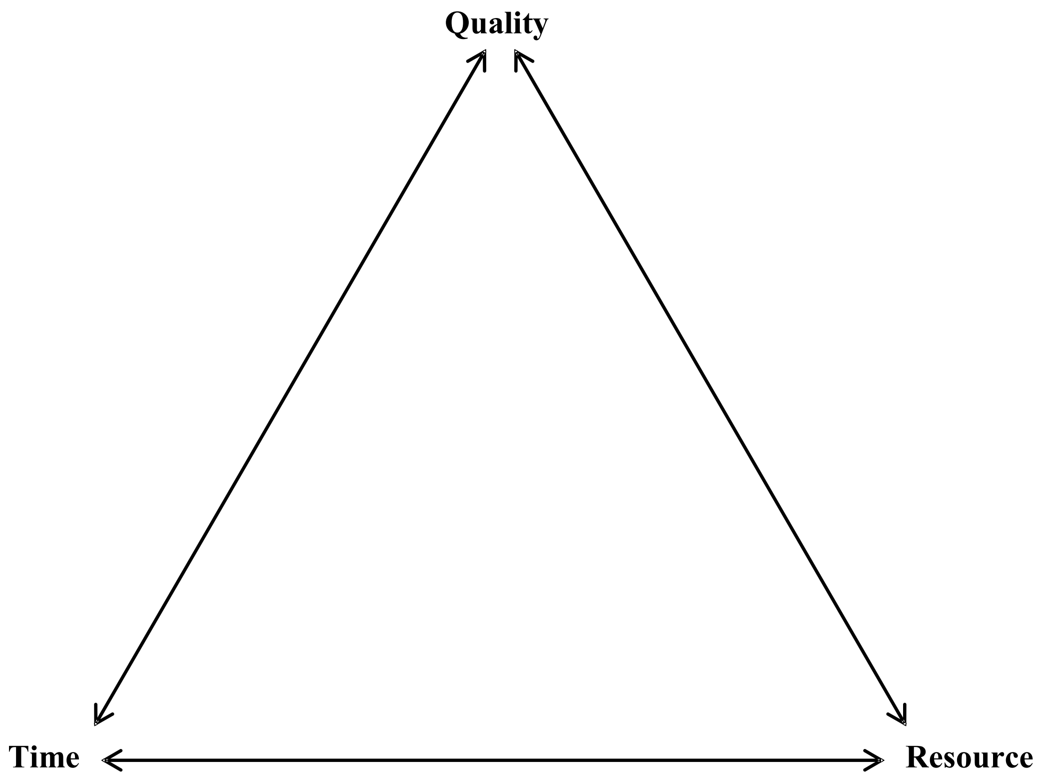


Figure 2: Abstraction Model of a Project

It can be argued that traditional SE focuses on delivering Quality, whilst Project Management focuses more on Time and Resource management. Eisner identifies a 'project triumvirate' of 'Project Manager', 'Chief Systems Engineer' and 'Project Controller' as performing a critical role in integrating a successful project [Eisner, 2002]. Each has a distinct role, but each must be capable of effective communication. Shinners points out that "The successful program manager must be a competent systems engineer, economist and manager" [Shinners, 1976: xix], emphasizing the overlap between SE and project (or programme) management. Systems Engineering Management, which plays a crucial role in ensuring the delivery of excellent SE projects, effectively describes the intersection of SE and Project Management.

3.7 (Specialist) Engineering

A dictionary definition of engineering is "the application of scientific principles to practical ends; as the design, construction and operation of efficient and economical structures, equipment and systems" [Kossiakoff and Sweet, 2003: 3]. A focus on value for money is therefore not peculiar to SE. Indeed, much of what is now described as SE is seen by some as just good engineering: "many systems practitioners do not believe that systems engineering is a separate discipline – instead they prefer to think of it as common sense, although they generally concede that such sense may be far from common" [Hitchins, 1992: 264]. Flagle, Huggins and Roy note that opponents of SE derided the subject as "nothing but people who can draw block diagrams or merely 'the engineering process' itself – that is, nothing new at all" [Flagle, Huggins, and Roy, 1960]. In the days before SE was established as a discipline in its own right, it was certainly the case that elements of 'Systems Engineering' would have been performed under the banner of just 'Engineering'. However, "industrial engineering lacked precedents for combining a number of professional disciplines in a single project effort" [Optner, 1973], highlighting the need for 'Systems Engineering'. Shinners [1976: xix] supports the distinction between systems engineers and specialist engineers, noting that the systems engineer "must have an adaptive capability which distinguishes him from the engineering specialist who is concerned with only one aspect of a well-defined engineering discipline". Incredible cross-disciplinary engineering projects were certainly completed long before the term 'Systems Engineering' was in popular use, though. From the start of the industrial revolution in Britain in the early nineteenth century to the completion of the Hoover Dam in 1935, there are countless examples of engineers achieving 'the impossible'. Often, however, 'the impossible' was achieved at great financial and human cost [Cadbury, 2003], and to a large extent SE's role has traditionally been to facilitate the delivery of spectacular feats of engineering without incurring spectacular costs. As the application of SE has grown, so the responsibility of traditional 'Engineering' for the delivery of cross-disciplinary projects has diminished. Now, according to the Guide to the Systems Engineering Body of Knowledge (SEBoK), "Science determines what is, component engineering determines what can be, and systems engineering determines what should be" [Bayhill, Brown, Buede and Martin, 2002]. Of course, this overstates the authority of systems engineering, which doesn't have the consciousness necessary to make value-judgments (determining 'what should be'). A more accurate statement would be '*Science* determines what is, *component engineering* determines what can be at component level, *systems engineering* determines what can be at system level, and *leaders* determine what should be'.

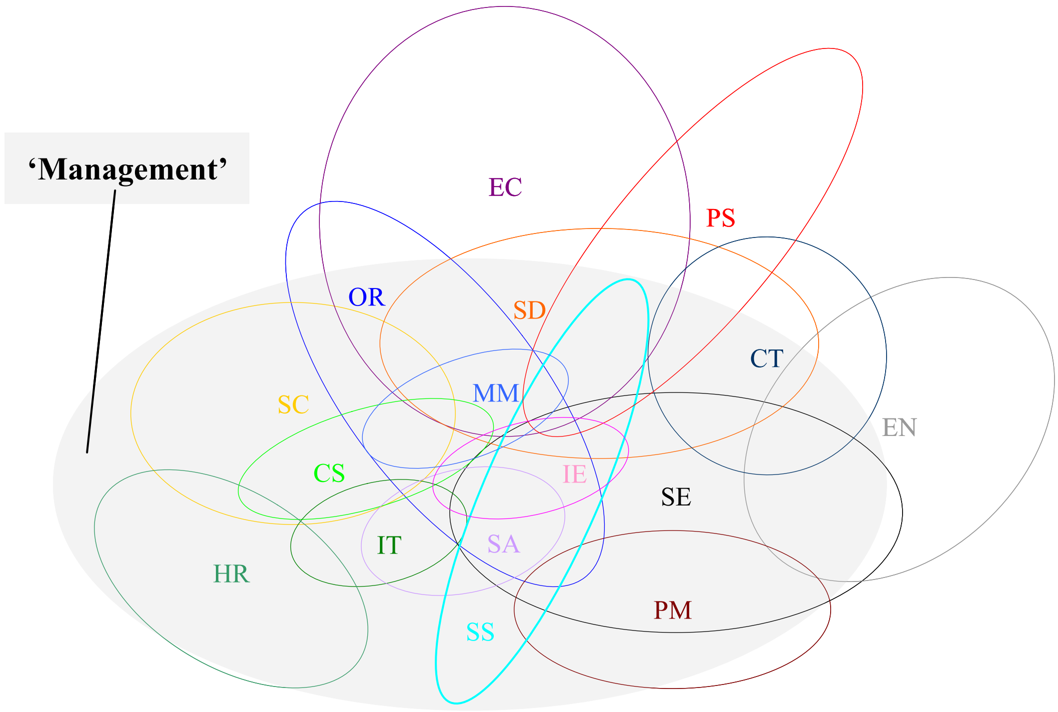
3.8 Control Theory

The IEEE Control Systems Society (CSS) was founded in l954 as a "scientific, engineering and professional organization dedicated to the advancement of the theory and practice of systems and control in engineering." Control systems focus on dynamic systems, with feedback a key concept. Values of system variables are sensed, fed back and used to control the system. The control law decision process is therefore based not only on predictions about the behaviour derived from the system model (as in open-loop control), but also on information about the actual system behaviour (closed-loop feedback control).

There is clearly a strong relationship between SE and Control Theory. One only needs to study the contents of the 'Journal of Systems Engineering (1991-1996)' or the 'Journal of Systems and Control Engineering – Part 1' (IMechE, 1991-present) to see that many deterministic dynamic systems can be usefully described and better understood by applying control theory. Much of modern 'Systems Engineering' lies outside the scope of Control Theory, though, in particular the focus on procedures, best practice heuristics and lifecycles. There is now probably more common ground between Control Theory and System Dynamics, which applies Control Theory to business and social systems.

3.9 Landscape of competing disciplines

Having ascertained that SE has areas of overlap with many other fields, it would be interesting to postulate a 'landscape' of fields (see Figure 3). A few fields that have no obvious direct overlap with SE are included for completeness. Note that there is no intended scale – the difference in shapes and sizes of the loops is merely intended to allow possible overlaps to be demonstrated. Of course, what one conceives the scope of each field to be strongly affects the position of the different disciplines within the landscape, and since many of the fields have rather loosely defined scopes, the landscape shown in Figure 3 is very subjective and open to debate.



Legend

SE – Systems Engineering	EN – (Specialist) Engineering
OR – Operations Research	IT – Information Technology
PM – Project Management	PS – Psychology
SA – Systems Analysis	EC – Economics
SD – System Dynamics	HR – Human Resource Strategy
CT – Control Theory	CS – Corporate Strategy
SS – Soft Systems Methodology	MM – Marketing Management
IE – Industrial Engineering	SC – Supply Chain Management

Figure 3: Landscape of disciplines 'competing' with Systems Engineering

With the landscape presented as in Figure 3, there is a part of the 'Systems Engineering' scope that is independent of other surrounding fields. This represents the competencies unique to SE. We can also consider the relationship between elements in terms of their 'building blocks' as in Figure 4.

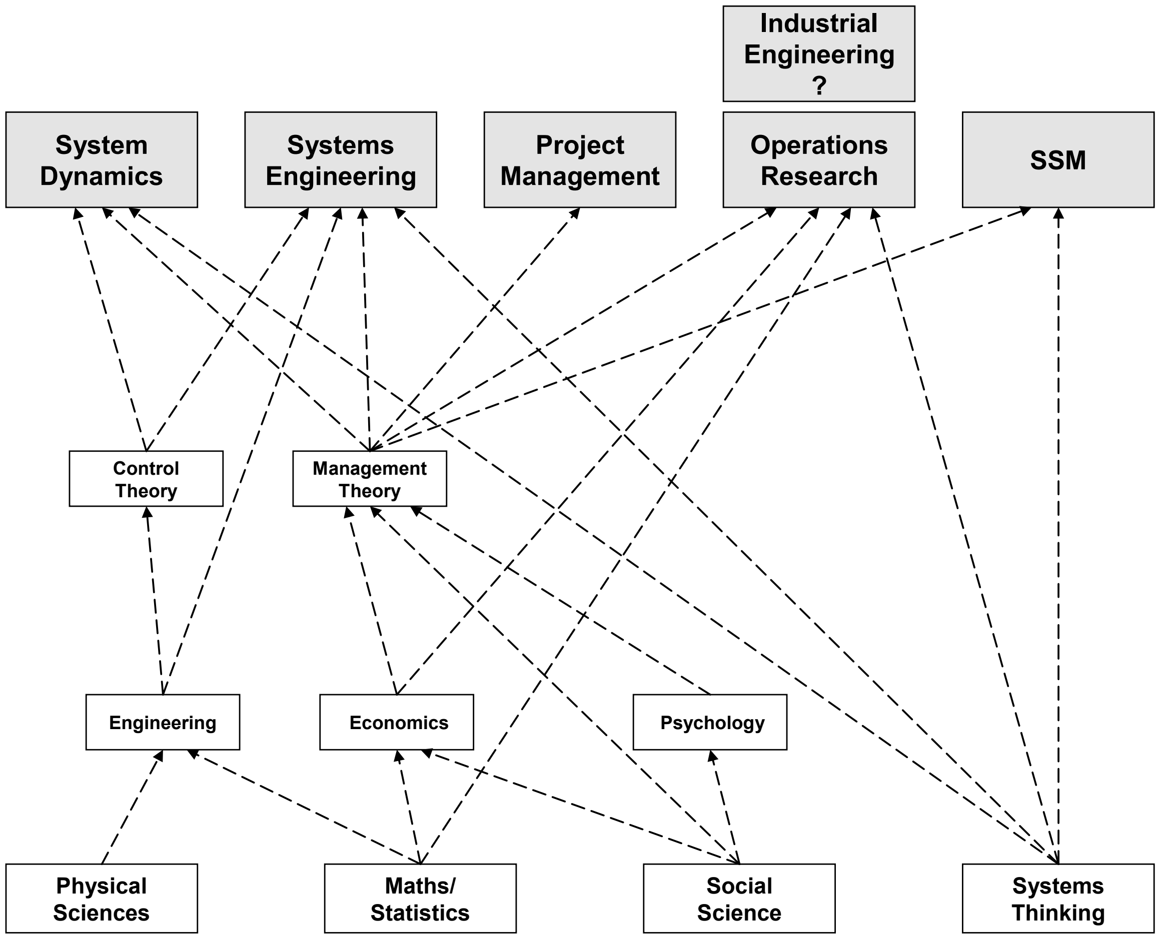


Figure 4: Roots of 'Systems' related disciplines

At the fundamental level these include the disciplines of the Physical Sciences, Mathematics, Social Science and Systems Thinking. The next level includes Engineering, Economics and Psychology, with Control and Management Theory dependent on more basic elements. It can be seen here that SE, System Dynamics and Operations Research share much ancestry, although the application domains vary significantly. Industrial Engineering is shown coincident with Operations Research although, as discussed in 3.2 above, some may argue that it has more in common with SE. It is interesting to note that 'Management Theory' is a component of all 6 disciplines, but the dependence on Control Theory, Engineering, Economics and Systems Thinking varies by discipline. Note that Systems Analysis is not shown on Figure 4 as the 'Systems' interpretation of Systems Analysis would see it subsumed within SE or OR, whilst the 'IT' interpretation would be outside the scope of Figure 4.

Having spent a little time trying to understand the scope and origins of SE as well as the other disciplines with which it has areas in common, we are now in a position to ask some fundamental questions of SE as a discipline.

3.10 How is Systems Engineering performing compared to other disciplines?

It would be useful to consider the relative sizes of some of the disciplines with which SE might 'compete'. The easiest way of doing this is by comparing the membership of the professional institutions that represent the disciplines. Table I shows the names, sizes and ages of some of the largest (US-based) international professional institutions that could be considered as competitors to SE in attracting members (membership information was obtained from institution websites and from personal communications with institutions).

Society	Representing	Established	Membership 2003 ('000)	Website
PMI	Project Management	1969	120	www.pmi.org
ISSS	Systems Sciences	1956	1.4*	www.isss.org
SDS	System Dynamics	1983	0.9	www.systemdynamics.org
IFORS	Operations Research	1952	30*	www.ifors.org
IIE	Industrial Engineering	1948	15	www.iienet.org
INCOSE	Systems Engineering	1991	4.8	www.incose.org
IEEE	Electrical and Electronic Engineering	1884	361	www.ieee.org
ASME	Mechanical Engineering	1880	116	www.asme.org
AIAA	Aeronautics and Astronautics	1931	29	www.aiaa.org
SAME	Military Engineers	1920	23	www.same.org
SAE	Automotive Engineers	1905	85	www.sae.org
SME	Manufacturing Engineering	1932	39	www.sme.org
AIChE	Chemical Engineering	1908	43	www.aiche.org
ISA	Instrumentation, Systems and Automation	1945	33	www.isa.org
ASCE	Civil Engineering	1852	133	www.asce.org
AIA	Architecture	1857	72	www.aia.org
NSPE	Professional Engineering	1934	50	www.nspe.org

*Estimated from sizes of member institutions

Table I: US-based international professional institutions

These institutions can be split into the categories of engineering institutions, and 'systems-related' institutions (including project management). INCOSE and the Institute of Industrial Engineering (IIE) could consider themselves as either (or both). The membership figures for 2000 and 2003 are shown graphically in Figure 5. It is clear that, compared to the large engineering institutions, INCOSE is very small, but is at least growing quite quickly. If we consider each institution's share of the total membership (Table II), we see that in 2000 INCOSE had 0.35% of the share, and in 2003 it had risen to 0.44%. If we consider INCOSE as an engineering institution and restrict our attention to engineering institutions, INCOSE's share of the total membership rises to 0.39% in 2000 and 0.51% in 2003 – a tiny but growing share of the total (Table III). If, on the other hand, we focus on 'systems-related' institutions, INCOSE's share is larger again – 3.04% in 2000, but falling to 2.75% in 2003 (Table IV). The fall in share of membership in 2003 is because of the very large increase in membership of the Project Management Institute. This has interesting implications for whether we view SE as competing more closely with other engineering societies or with systems based societies for members.

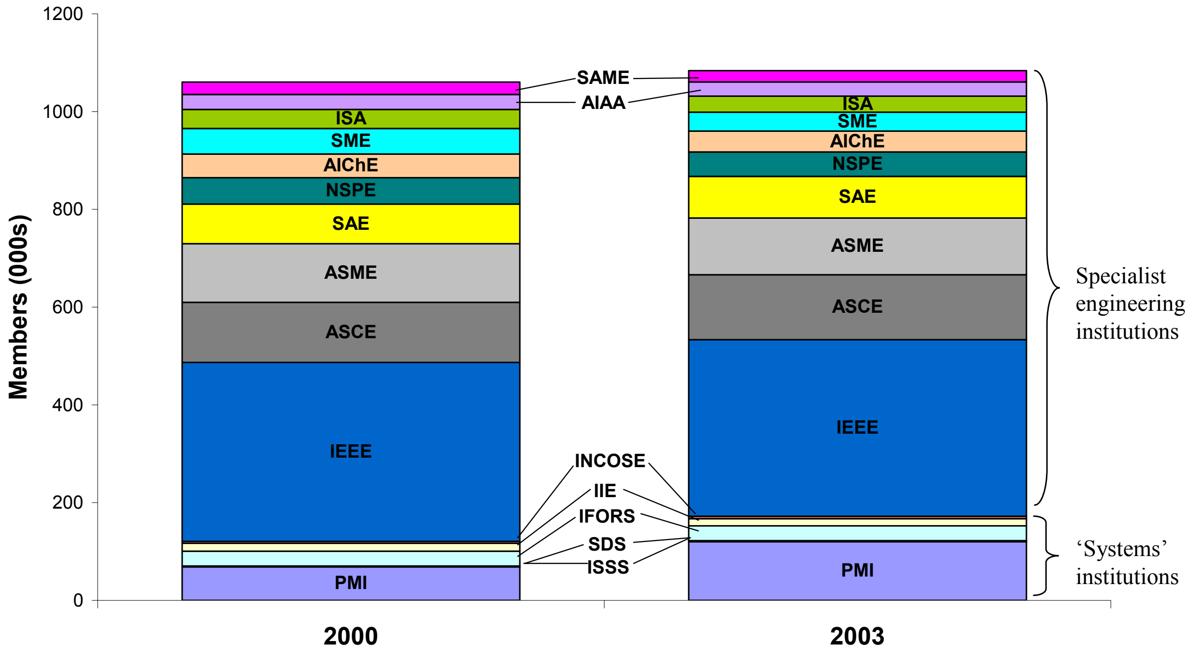


Figure 5: Sizes of professional institutions, 2000 and 2003

	2000	2003
PMI	6.4%	11.1%
ISSS	0.13%	0.13%
SDS	0.07%	0.09%
IFORS	2.8%	2.8%
IIE	1.6%	1.4%
INCOSE	0.35%	0.44%
IEEE	34.5%	33.3%
ASME	11.3%	10.7%
AIAA	2.9%	2.7%
SAME	2.4%	2.1%
SAE	7.6%	7.8%
SME	4.9%	3.6%
AIChE	4.6%	3.9%
ISA	3.7%	3.1%
ASCE	11.6%	12.3%
NSPE	5.1%	4.6%

Table II: All Institutions

	2000	2003
IIE	1.7%	1.6%
INCOSE	0.39%	0.52%
IEEE	38.1%	38.8%
ASME	12.5%	12.5%
AIAA	3.2%	3.1%
SAME	2.7%	2.5%
SAE	8.4%	9.1%
SME	5.4%	4.1%
AIChE	5.1%	4.6%
ISA	4.1%	3.6%
ASCE	12.8%	14.3%
NSPE	5.6%	5.4%

Table III: Eng.Institutions

	2000	2003
PMI	56.6%	69.7%
ISSS	1.16%	0.81%
SDS	0.65%	0.54%
IFORS	24.8%	17.4%
IIE	13.7%	8.7%
INCOSE	3.11%	2.80%

Table IV: 'Systems' Institutions

Shares of Membership by professional institution (2000 and 2003)

We can examine the growth of the institutions using the Boston Consulting Group (BCG) Growth-Share matrix (explained in Kotler [1997: 72], for example). This is really intended to examine and categorize an organization's portfolio of business interests to determine where to invest more money and which enterprises to get rid of. Business units are plotted as bubbles on a chart with the *x*-axis representing the market share of each business unit relative to its biggest competitor, and the *y*-axis representing the market growth rate. The area of the bubble represents the size of the business unit.

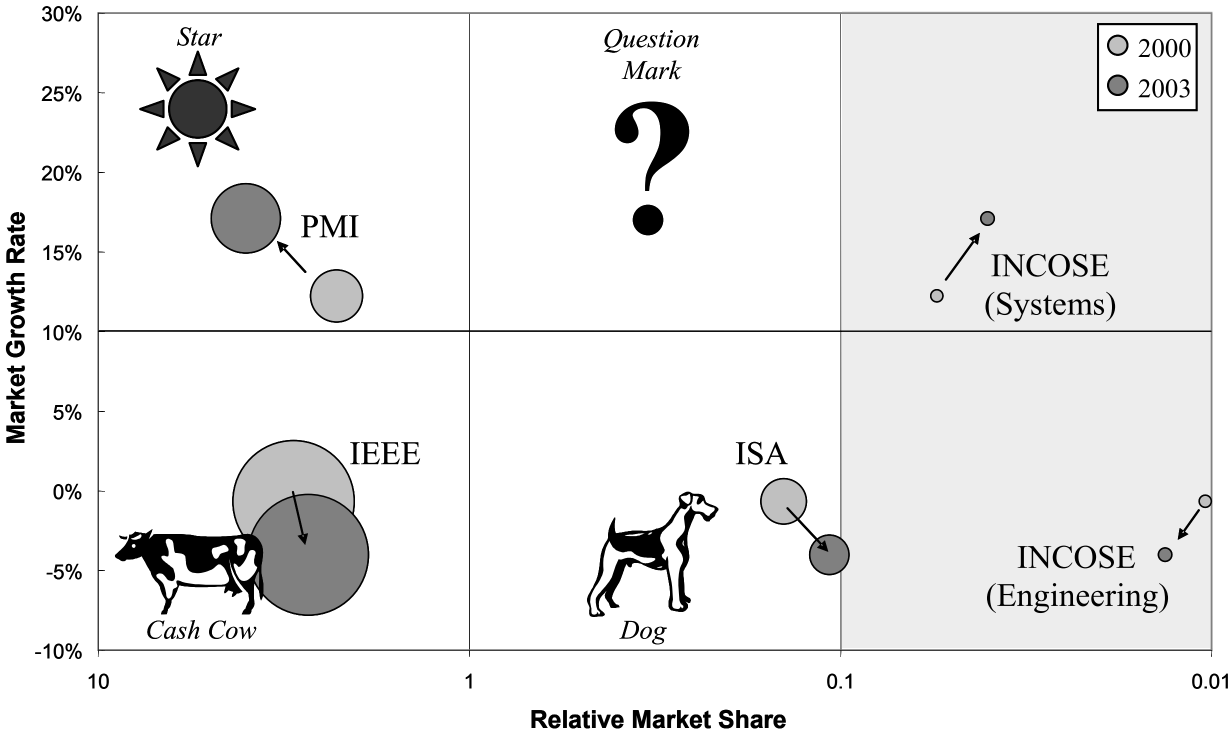


Figure 6: Growth-Share Matrix for Professional Institutions

Although it isn't using the model as it was originally intended, the growth-share matrix can be used to map the relative performances of the different professional institutions, by taking the 'market' in each case to be the relevant institutions with which each professional body competes for members and the area of each bubble to be the membership of the institution it represents (Figure 6). Such a comparison might be interesting for organizations that invest heavily in different types of engineering, or for students considering careers in different fields.

According to the BCG system, INCOSE would be classified as a ‘Dog’ if it were viewed as an engineering discipline, since it has a weak (but rising) relative share in a low growth market (negative growth in this case). A company should consider whether it is holding onto a ‘Dog’ for good business reasons such as an expected reverse in the market growth rate or a chance of market leadership. Neither of these seems plausible for INCOSE, so an investor in SE as an engineering discipline would have to think seriously about whether to continue to back it.

INCOSE would be classified at best as a ‘Question Mark’ if viewed as a ‘systems’ discipline, since it has a low (but falling) relative share in a growing market. In fact, INCOSE is so small relative to other engineering and systems institutions that it wouldn’t even appear on the chart if we used the conventional *x*-axis range of 0.1 to 10 (hence the greyed out area on Figure 6). Most businesses start off as question marks, entering high-growth markets in which there is already a market leader (in this case, PMI). Question Mark businesses require a lot of investment to keep up with the established market leader. In the case of INCOSE, most of the investment needed is in promoting the merits of SE (or promoting the SE ‘brand’) to potential customers. The other two quadrants of the growth-share matrix represent ‘Stars’, market leaders in high-growth markets which also require substantial investment to keep up with the fast-growing market, and ‘Cash Cows’, market leaders in low growth markets which generate high profit for businesses.

So even though INCOSE is growing fast, it has a tiny share in a declining market if we consider it an engineering discipline. In the best case if we view it as a systems/management discipline it has a low and shrinking (in relative terms) share in a growing market. This has striking implications for how INCOSE should brand itself if it is to survive in the long term (as a systems/management discipline or as a systems/engineering discipline). It also suggests that SE is not being ‘sold’ very well at the moment to potential ‘customers’ for systems/management ideas.

4 What sells Systems Engineering?

Cowper and Smith identify the key barriers to promoting and ‘selling’ systems engineering as: the lack of SE awareness and understanding, the lack of a clear message about what SE is or is not, the confusion over the Systems Engineer’s skill set, the need for a business case for

SE, and the management of implementation risks [Cowper and Smith, 2003]. The first three of these barriers could be classed as 'branding' issues. It has also been argued that the adoption of SE has been restricted by its limited appeal to universities: "because operations research and systems engineering borrowed their methods from other disciplines, and were commonsense – that is, procedural – disciplines themselves, their claims to academic legitimacy were tenuous" [Johnson, 1997: 913]. Worse still, neither OR nor SE could point to a clear theoretical or empirical base. Johnson notes that "traditional disciplines, such as biology, physics, and mechanical engineering, demarcated boundaries by their claim to theory of or application to specific natural or physical phenomena. Others, such as mathematics and control theory, identified with unique theories and mathematical methods, even if broadly applied. Operations research and systems engineering were hampered on both counts" [Johnson, 1997: 913].

Whilst SE, fundamentally viewed as an engineering discipline, struggled to be accepted into the academic curricula of engineering degrees, project management enjoyed much greater success in being adopted by business schools. "Because business schools focused their attention at least in part on procedural knowledge, project management was an acceptable, easily accommodated change to business school teaching and research. By contrast, procedural knowledge was (and is) consistently underrepresented and undervalued in the mathematically oriented curricula of science and engineering departments" [Johnson, 1997: 915]. Perhaps SE would enjoy greater success if it, too, were taught in business schools as a management skill rather than in engineering departments? Wherever we want to 'sell' SE, though, we need to define clearly what we are talking about and to distinguish SE from other related disciplines.

4.1 What is unique about Systems Engineering?

If we can agree that there are certain areas that SE has in common with other fields, we must next address the question of what components of 'Systems Engineering' are unique to this field. Perhaps there are no such elements unique to SE, and SE is defined merely by the combination of techniques that it employs?

The INCOSE UKAB (United Kingdom Advisory Board) is investigating the 'core competencies' of SE and has found these to be: 'Systems Thinking', 'Holistic Lifecycle

View' (including system design, integration, validation etc.), 'Systems Engineering Management' (concurrent engineering; plan, monitor and control, etc.) and 'Interdisciplinary'. Clearly, 'Systems Thinking' is not unique to SE (see Figure 4). One could argue that a unique competency with SE is its 'Interdisciplinary' approach. But is it fundamentally any more interdisciplinary than the task facing an electronic engineer who has to integrate different types of electronic components on a circuit board? Surely this is just 'Systems Engineering' on a component level. Perhaps, then, it is the fact that historically our engineers have not had a broad enough engineering education that means that we see designing a spacecraft with electrical, thermal and mechanical constraints as a task for a systems engineer, whilst we see designing a circuit board with resistors, capacitors, etc. as a task for an electronic engineer.

Good engineering requires not just good knowledge of specialist engineering disciplines such as Mechanical Engineering, Civil Engineering, etc., but also complementary knowledge such as Systems Engineering, Economics and Management (see Figure 7). If universities taught general engineering courses instead of specialist courses, and retained an element concerning overall system design (as opposed to teaching a 'general engineering' course by breaking it down into 'mechanical engineering', 'civil engineering', etc. and teaching these parts independently), then surely an understanding of 'Systems Engineering' would automatically be developed. That SE is interdisciplinary, whilst undisputedly true, may therefore be something of an artefact of the way we teach engineering.

Maybe the essence of SE lies in the Holistic Lifecycle View, or in Systems Engineering Management? Perhaps, but even these contain significant elements of Project Management, albeit with peculiarities derived from the technical domain in which SE is mostly practised. Perhaps SE's competencies are truly unique, then, only in the way that they are combined. If SE has no unique core competencies, Figure 3 should really be redrawn with no part of SE not overlapping with one or more surrounding disciplines. This has interesting implications. It suggests that if we put together a team of experts including one from each of the disciplines in Figure 3, then we could afford to do without the expert in SE, as his or her expertise would be completely covered by the remainder of the team. The critical importance of the Systems Engineer, though, is often not in possessing unique knowledge, but in possessing a diversity of knowledge from several different domains that allows that person to make holistic trade-offs and judgments that no other individual in the team could make.

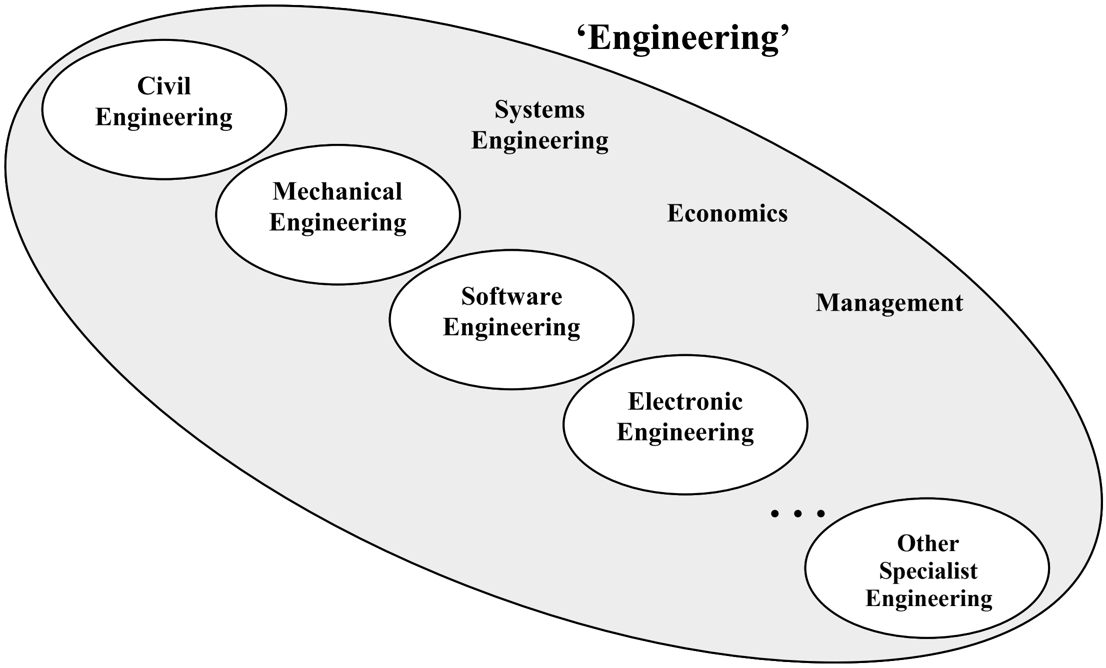


Figure 7: Partitioning Engineering

Kossiakoff draws an analogy between military campaigns and large systems projects, characterizing the systems engineer as a technical general who understands the language of specialists and coordinates the team [Kossiakoff, 1960]. Successful coordination relies on the ability to communicate in both directions with a diverse range of team members and external stakeholders. When receiving information, this requires empathy and an understanding of the information provided. When giving information, this requires empathy and a way of communicating information and decisions in a language that will be understood. This ability is arguably more important for the systems engineer than for any other team member. Unless the system engineer understands the language and needs of each other team member, each other team member will have to be educated in SE, which is unrealistic (in the short term at least). Sacrificing the systems engineer might seem possible, but in reality would seriously hamper the performance of the team.

5 Who sets the scope of Systems Engineering?

The next question we should address is who decides what SE is? Since SE cannot point to a clear theoretical or empirical base [Johnson, 1997: 913], its definition is open to interpretation and manipulation. Who should do the interpreting? Is it the body that represents it, namely INCOSE, or is it the practising engineers? Of course, in an ideal world the objectives of INCOSE's leadership and of its members would be continuously and perfectly aligned, but it would be idealistic to assume that this happened in practice. Perhaps 'Systems Engineering' is simply the activity of people who call themselves systems engineers? Or did the practice of SE predate the existence of people who thought of themselves as systems engineers? The latter seems more likely and indeed is supported by the Oxford English Dictionary's definition of SE: "the investigation of complex, man-made systems in relation to the apparatus that is or might be involved in them; so systems engineer" [Simpson and Weiner, 1989]. This view is supported by the INCOSE Systems Engineering handbook, which defines a systems engineer as "An engineer trained and experienced in the field of Systems Engineering" [Whalen et al, 2000].

Figure 8: The logical link between systems engineer and Systems Engineering

It seems possible, though, that whilst the discipline of SE predates the existence of systems engineers, the discipline of SE has since evolved to include all of the activities undertaken by people who now see themselves, rightly or wrongly, as systems engineers. This begs the question: 'what is the logical link between systems engineers and SE?' We could certainly say, as in Figure 8, that a systems engineer performs SE as it is clearly true to say that all systems engineers must perform some SE. It is rarely true to say that all of the SE performed within an organisation is done by people with the job title 'systems engineer', though. Neither is it generally true that 'systems engineers' spend all of their time doing 'Systems Engineering'. But assuming that the scope of SE is malleable, and recognising INCOSE's unique position to influence this scope, one wonders whether INCOSE should define the scope of SE via points of principle or under the influence of 'customer' demand? A similar conundrum faces politicians when determining party policies. It could certainly be argued in the United Kingdom, for example, that Tony Blair's Government alienated traditional Labour Party supporters by moving away from its socialist roots towards the centre-ground of politics, where the 'demand' was greatest. It is dubious that the Labour Party changed its stance merely due to a change in principles of the party's leadership; it was influenced by the needs of the 'customer' – the voter. Is it INCOSE's responsibility to define the scope of SE? If so, has it provided a definition satisfactory to its stakeholders? Who are INCOSE's stakeholders, by the way?

6 Who are the stakeholders of Systems Engineering?

Searching INCOSE's website revealed several documents which referred to INCOSE's stakeholders, such as INCOSE Strategic Directions [Rhodes, 2002] and INCOSE's 2002 annual report [INCOSE, 2002]. Strangely, none of these included a list of who INCOSE thought its stakeholders actually were. Luckily, inferring who INCOSE thinks its stakeholders are is not too difficult from the 'Strategic Directions' document. Since INCOSE represents systems engineers, perhaps its primary stakeholders are the engineers and industries that it represents. But if the purpose of INCOSE is to *represent* systems engineers' interests, then one could argue that the most important stakeholders of INCOSE are not the systems engineers but the 'customers' of SE – i.e. government, public and private organisations and the general public, all of which rely on the provision of SE. INCOSE should therefore be concerned with ensuring that quality work is delivered to the buyers of SE services, and to grow the demand for SE services. In practice, INCOSE surely has to keep its members happy in the short term, whilst keeping customers of SE happy in the longer term (without upsetting its members!) A combination of initiatives will be necessary to satisfy both sets of stakeholders. Note that the number of members of INCOSE is not a particularly useful metric for measuring the level of satisfaction of INCOSE's stakeholders. The fact that INCOSE membership is growing does not necessarily mean that SE is doing a great job of satisfying stakeholders (it could achieve the same effect by dropping the membership fee for new entrants to $1, for example). Furthermore, many of INCOSE's stakeholders (in particular the customers for SE) would not want to be members of INCOSE. We should next consider how INCOSE should position SE in order to satisfy its stakeholders.

7 How should Systems Engineering position itself within this landscape?

To put this another way: what should SE try to be, and what should it not try to be? Perhaps we should also ask ourselves: what should INCOSE's role be? If it is to serve its stakeholders well, INCOSE should focus on creating as much value as possible for the customers and providers of SE. But how can it achieve this? There are two limiting strategies. At one end of the spectrum, SE could focus on a small niche market and perform activities that no other discipline can offer within this market. At the other end of the spectrum, SE could attempt to target a much broader market and address problems that other disciplines might traditionally answer. The scope of traditional hard SE was nearer the first end of the spectrum, focusing mainly on technical military and aerospace projects. Today, we seem to be moving away from hard SE and the mature engineering market, perhaps seeking the growing market of systems thinking and systems management. Is this change in emphasis being managed? How broad a scope should SE ultimately take on?

For too long, SE's scope and purpose have been poorly defined. It seems strange given SE's apparent early promise [Jenkins and Youle, 1971] that it took thirty-four years after the first SE textbook was published for (I)NCOSE to be established [Honour, 1998]. But now that INCOSE is established, can we expect SE to be managed more strategically in the future? INCOSE certainly has strategic intentions, having established a 'strategic planning framework', which is described in its annual report [INCOSE, 2002] and having published its 'Strategic Directions' [Rhodes, 2002]. The latter is particularly interesting; it includes a list of strategic priorities: to "gain further recognition by industry, government, academia, and other professional societies of the importance of systems engineering; achieve wide acceptance of INCOSE as the leading systems engineering society, and position INCOSE as a unifying force across engineering communities and specialties; to provide high value products and services to (INCOSE) members and corporate sponsors, and opportunities for professional networking; to promote growth through diversification of (INCOSE) stakeholders, products, services, and initiatives; to provide the infrastructure and a well-balanced leadership organization to accomplish targeted initiatives, and attract highly qualified leaders for all leadership positions". It seems, then, that INCOSE now has the architecture in place to effect strategic changes, and to guide the SE profession. What is not so clear, though, is how INCOSE sees SE's role relative to overlapping disciplines and their professional societies. Should SE try to broaden its scope and try to answer 'soft systems' questions, for instance, or should SE focus on its traditional strength – the development of excellent technical systems?

Jenkins and Youle [1971] note that "a systems approach is centred round the human being; … the efficient design of systems is influenced decisively by the people who have to operate them". Perhaps this crucial dependence on humanity will limit the ultimate achievements of SE, and our aspirations for the profession should reflect this. After all, humans simply aren't very good at making decisions. There is no end of evidence about the limitations of human cognitive capability (for example, Miller [1956]). Even highly trained humans make mistakes, but the average human's sheer 'humanity' is simply depressing. Susceptibility to social pressures [Hogg and Vaughan, 2002], cognitive limitations [Reisberg, 2001] and misleading heuristics [Kardes, 2002] lead the casual decision maker astray. Even the careful decision maker can at best be described as having 'bounded rationality' – building simplified models of reality and making decisions based on these models, which usually prove to be wholly inappropriate [Simon, 1957]. Poor decision making is not just bad value for money - it is dangerous. Analyses of industrial accidents have found that around 80% are caused by 'human errors' [Rasmussen, Pejtersen and Goodstein, 1994: 135].

Despite the problems associated with humans in systems, systems engineers seem recently to have warmed to Soft Systems Methodology and 'Human Activity Systems' [Wilson, 2001]. This is no more within the domain of (hard) SE than are Operational Research or Systems Dynamics, for example, yet these disciplines receive little attention from systems engineers. One wonders whether the warming to SSM is because it is seen as interesting, accessible and requires limited formal training, particularly since it is not very quantitative. Sadly, that it is not quantitative does not mean that it is not difficult; any system involving humans is many times more complicated than the relatively predictable world of traditional engineering, and becoming an 'expert' in the systems approach may be an elusive goal. Churchman [1968: 231] concludes that "the systems approach begins when first you see the world through the eyes of another … The systems approach goes on to discovering that every world view is terribly restricted" and ultimately finds that "There are no experts in the systems approach".

Furthermore, there is a danger that traditional SE could 'deskill' by becoming too familiar with SSM. Whilst OR was accused of 'mathematical masturbation' [Ackoff, 1979] and marginalized its contribution through lack of real world application, perhaps too great a familiarity with SSM would put SE in danger of the reverse – watering down its quantitative rigour with common sense heuristics. This could make it even harder for universities to accept SE as an engineering discipline. Systems science has its roots in biology and control engineering [Checkland, 1981], but seems in danger of becoming purely social science, with more 'social' than 'science'. It is all very well saying that we should ignore questions of terminology and definition, embracing all of the disciplines that overlap with SE, but by doing this SE risks losing focus on what it is, and what it is good at. Furthermore, it paints a confusing picture to outsiders trying to understand the distinction between SE, SSM, System Dynamics, OR and IE, for instance. Is the apparent warming to soft systems a conscious strategic decision on the behalf of INCOSE and/or the scientific community of systems engineers (for who else steers the ship)?

Operations Research seems to have lost momentum in the last two decades, and SSM, too, now seems to be sailing over turbulent waters. Its most well-known practitioners seem to share disillusionment with its achievements, but differ in their emphasis on the cause of its failings. Whilst Checkland suggests that a lack of rigour in the application of SSM and in the understanding of its core concepts has stifled its growth [Checkland, 2002], Mingers suggests that SSM could have been more successful if used in conjunction with other techniques [Mingers, 2002]. Mingers argues that much of Checkland's application of SSM is seen as 'isolationist'. Given the overlap of interest between 'systems societies' and INCOSE discussed in Section 3.5 above, does INCOSE see systems societies as competitors or as potential collaborators? Lane argues that "today, system dynamics is perhaps at its most confident. At the same time, because it aspires to deliver so much, the field is entering a high-risk period in which it risks an 'overshoot and collapse' mode … if it is unable to deliver convincingly on those promises. Collapse might occur because of our isolation from other techniques" [Lane, 1994]. What has SE learnt from the successes and failures of other systems disciplines? Furthermore, how do the expected future activities of these disciplines influence the optimal positioning of SE? As a discipline, it should not simply drift over time; there needs to be a long term strategy for what SE is and what it aspires to be. SE needs to be managed as a 'brand', establishing its Points of Difference (like unique selling propositions) and Points of Parity (features deemed necessary by consumers to 'compete' in the marketplace) with other 'brands' [Keller, 2003].

Interestingly, INCOSE UK signed a Memorandum of Understanding with the Institution of Electrical Engineers (IEE) on the 14th October 2003 to encourage (further) collaboration between the two societies, including among other things: "Promotion of Systems Engineering as a technical discipline…; Professional development of Systems Engineers … leading to internationally recognised status; Joint sponsorship of events…" (http://www.incose.org.uk/mou-iee.htm). The IEE has also established a 'Professional

Electronic Network for Systems Engineering (PeNSE)'. There is therefore some momentum (in the UK at least) towards closer partnership with the specialist engineering societies. Why INCOSE UK's strategy is to pursue closer links with the IEE but not, for example, the Project Management Institute or the UK Systems Society, is not obvious.

INCOSE's strategy for partnering with other institutions should be clarified, as a lack of purposeful direction in such a critical area could have disastrous consequences. De Geus [1999] identified that even large organizations can die. "If you look at them in the light of their potential, most commercial corporations are dramatic failures – or, at best, underachievers … The average life expectancy of a multinational company – Fortune 500 or its equivalent – is between 40 and 50 years ... A full one-third of the companies listed in the 1970 Fortune 500, for instance, had vanished by 1983 – acquired, merged or broken to pieces." De Geus looked into the characteristics of long-lived organizations and found them to be: (i) sensitive to their environment (ii) cohesive – with a strong sense of identity (iii) tolerant to exploring the boundaries of their activities (iv) conservative in financing. Interestingly, return on investment and longevity were uncorrelated. Small organisations can be even more vulnerable. The implication of this for INCOSE and its constituent chapters is stark: continue to adapt and evolve, or die. How well would INCOSE score against De Geus' four characteristics of long-lived organizations? INCOSE's membership has risen impressively since its conception in 1990, but strategic directions determined now will determine the fate of the organisation in ten years' time. We must therefore continue to learn even when we seem to be growing. Senge [1990] notes that organizations' inability to learn can be fatal: "Perhaps under the laws of 'survival of the fittest', this continual death of firms is fine for society…But what if the high corporate mortality rate is only a symptom of deeper problems that afflict all companies, not just the ones that die? What if even the most successful companies are poor learners – they survive but never live up to their potential?" Senge proposes five disciplines of the learning organization: "systems thinking, personal mastery, mental models, building shared vision and team learning". It seems appropriate that Systems Thinking should be identified as one of the disciplines that can ensure the survival of SE. Furthermore, the popularity of Senge's ideas has put Systems Thinking on the radar of senior management thinking, which is to be welcomed. But nearly 15 years after Senge identified its importance, the opportunity still hasn't been seized and developed. For too long, Systems Thinking has been waiting patiently outside the boardroom; now it's up to the SE community to figure out its sales pitch.

Perhaps, ultimately, the SE community could do a better job of practising what it preaches, by applying systems thinking to the question of how to position SE strategically. SE as a discipline can be thought of as an organism that must adapt to its environment in order to prosper and survive. This is certainly true of INCOSE. It seems like SE has been skulking in the shadows for a long time now, with no clear identity, and poor understanding of its scope and purpose, particularly amongst those outside the SE community. SE is faced with a stark decision: whether to attempt to expand its scope, with INCOSE possibly attempting to embrace elements of neighbouring disciplines to form a coherent SE or Systems Management society (as it is apparently already doing with soft systems thinking), spreading the gospel of SE into the world of management, or whether to refocus on its traditional strengths, namely the development of technical systems that span traditional engineering disciplines. If SE is to expand its scope, it will encroach on the neighbouring disciplines of Project Management, Systems Dynamics, Systems Analysis, Engineering, Economics, Operational Research, IE, SSM, IT, Control Theory and Marketing Management. Some of these areas (Engineering, Project Management, Control Theory, Systems Analysis) represent more traditional areas of 'hard' SE. Other areas such as SSM, Systems Dynamics, Economics and Marketing Management would be relatively novel fields for SE to explore. Either way, we must define SE's scope clearly (but not microscopically in an endless navel-gazing exercise), recognising and managing carefully the overlaps with other fields. We must do more than merely acknowledge that not everyone that engages in Systems Engineering is called a Systems Engineer.

8 Conclusions

The authors would not advocate a return to the academic disputes of the 1950s over the scopes of the different 'systems' subjects [Johnson, 1997: 909]. But, for the sake of those outside the SE community, we need to clarify what SE represents. Hughes notes that "Americans take the 'West' and the 'machine' as symbols providing perspectives on their early and recent history. After a century of system building, they might as well see the 'system' as their hallmark" [Hughes, 1989: 185]. Why, then, does SE receive so little recognition compared to more established engineering disciplines and project management? There seems to be a consensus that SE truly does make a valuable contribution to the management of scientific developments. The only logical conclusion is therefore that the SE community is not doing a good enough job of ‘selling’ its achievements and its competencies to the world at large.

Let us imagine that we were outside the SE community looking in. What would make us want to embrace SE? First impressions would be important; a strange creature lurking in the shadows would turn us away. We would want to turn on the lights and look this beast in the eye. Once we understood what the creature was and felt we could introduce it to our masters (stakeholders) without embarrassment, SE would have a foot in the door. Only then would we care whether SE could provide a quality product or service (which it can), and whether it represented good value for money (the proof of which INCOSE’s (2002) Corporate Advisory Board (CAB) has identified as its top priority). Getting the foot in the door is largely a question of brand positioning and advertising, a puzzle which SE has failed to solve so far.

A three-pronged attack is suggested to scatter the shadows and dispel the mystery of SE. Firstly, work must continue to define the core competencies of SE. The work by the INCOSE UK Advisory Board, for example, should be supported to define what the essence of SE really is. Secondly, INCOSE should take a strategic view on which of the overlapping fields it wants to embrace, in particular answering the questions of whether soft systems analysis is considered formally within the scope of SE and whether SE is fundamentally a management discipline or an engineering discipline (because this affects where it should be taught). In doing this, INCOSE should trade off the benefits of reaching a larger market with the potential costs of spreading SE thinly over diverse fields, which may paint a confusing message to outsiders (as SE is currently defined). Thirdly, having taken a position on what surrounding disciplines INCOSE considers applicable to SE, INCOSE must associate with these disciplines more actively, such as through more shared conferences and publications and through concessions on memberships to related professional societies.

Once we’ve decided what modern SE really is, it might be appropriate to consider whether the words ‘systems’ (which is misunderstood and in a complex world not very descriptive) and ‘engineering’ (an exciting term in the heady days of the industrial revolution but less fashionable in today’s knowledge-based, service-driven economy) are still the best words to label it.

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