Keynote Address for ASEC 2014

Respice, Adspice, Prospice

(Look back, look around, look forward)

by

Derek Hitchins

Introduction

This occasion being the 20th anniversary of the start of the UK Chapter of INCOSE, it seems appropriate to review our progress:

- How far we have come
- Where we are now
- Where we are headed…

…hence the Latin title, after my old school motto—sorry!

Respice

Or, how far have we come since the 1940s, when Systems Engineering began in earnest? We could have started in c.1990, when NCOSE was founded, but there has not been so much noteworthy Systems Engineering on-the-grand-scale since then—compared, that is, with what went before. Except, perhaps, the Channel Tunnel, the Scottish Parliament Building, the Typhoon, London Underground, and a few others…

Figure 1 shows a cursory timeline for UK Systems Engineering, focusing principally on UK defence activities, but with major US Systems Engineering activities included for cross-reference.

There are four parallel timelines, one each for: UK Air Defence (UKAD); RAF Fighter Interceptors; INCOSE; and, significant US projects. UKAD starts with the Battle of Britain that, with its innovative Chain Home radars to detect imminent raids, use of Royal Observer Corps, innovative Command and Control, and rapid deployment of Hurricanes and Spitfires, constituted a novel Air Defence System that evolved while in operational use, to match the German offensive; *just*.

The 1960s saw Linesman/Mediator, a combined military UKAD and civil air traffic management system. Linesman was the military part, and it was highly sophisticated —perhaps too sophisticated for the then technology.

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The threat that Linesman faced was dire. The Soviets were believed to have nuclear-tipped standoff weapons, to be launched some 100nm or more from our east coast, from up to 100 Soviet aircraft *simultaneously*. So, that constituted a *problem!*

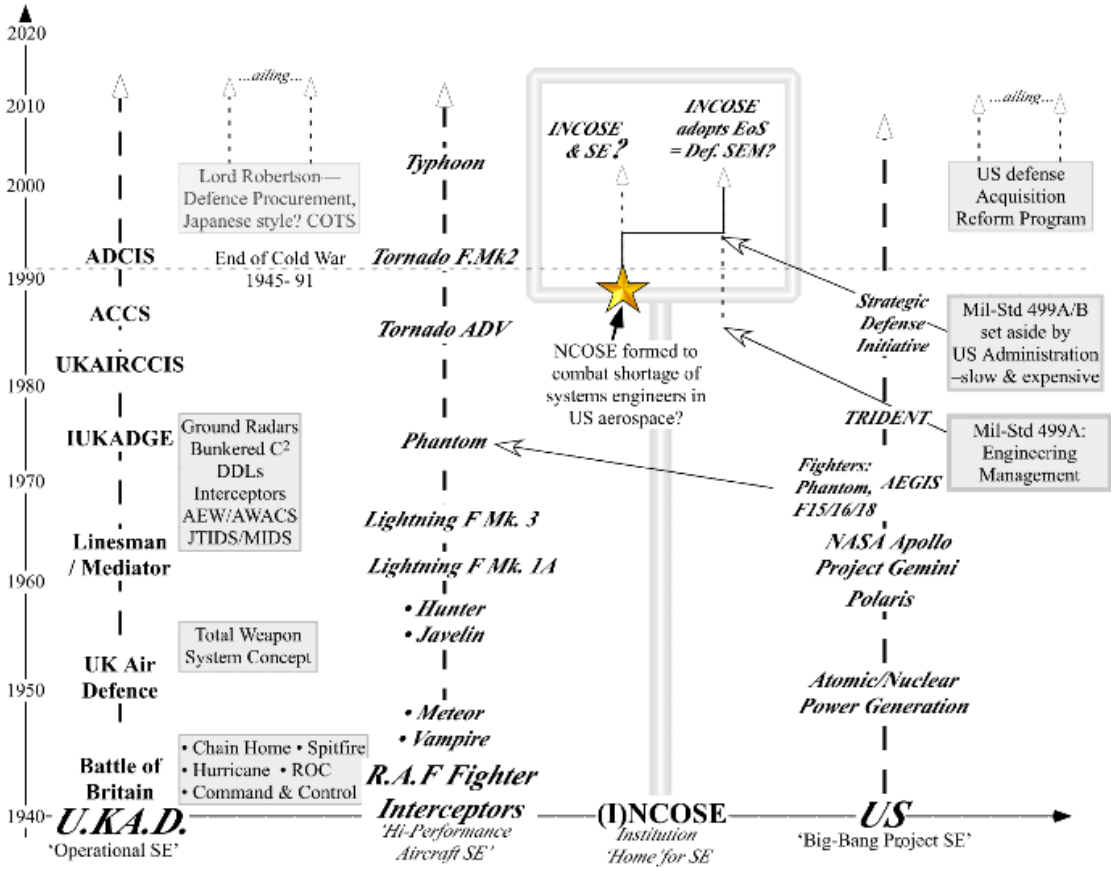

Figure 1. Timeline for UK/US Systems Engineering

Linesman was an example of the so-called Total Weapon Systems Concept in action. The whole of this vast organization of various technologies and people was viewed as one single system, with one singular purpose: to defend against the Soviet threat of standoff missiles that could be launched from an armada of Soviet bombers some 100nm from the UK coastline. These bombers were to be accompanied by standoff radar and communication jammers. Altogether, a formidable threat…

Linesman comprised a number of major subsystems:

- Half a dozen advanced, high-powered radar sites on the UK's east coast, with Type 84 and Type 85 radars at each site, fitted with advanced anti-jamming capabilities and 3D performance, forming the ground-based sensor system.
- Airborne Early Warning aircraft, designed to detect low flying Soviet aircraft sufficiently far from the coast to permit interception in time, and forming the airborne sensor system.
- Transmission of the radar information from all sites and AEW to a central location where a single dynamic Recognized Air Picture (RAP) could be formed, covering the whole of the UK and its approaches, particularly from the East.
    - From the RAP, there was a central control system, with controllers to mark targets, allocate Interceptors to them and control the Interceptors flight path towards the point of target engagement—automatically.

- Ground-to-ground and ground-to-air digital data links carrying both discrete target and intercept flight direction data from the RAP to as many as 100 Lightning interceptors operating simultaneously to engage 100 individual soviet bombers with their standoff missiles, hopefully prior to launch:
    - The ground-to-air data link used extremely high-powered transmitters, sufficient to overcome the known power of the soviet standoff jammers
    - The data link transmitters were co-located with the ground radars
- The Lightning aircraft, potentially Mach 2+, were capable of being controlled fully-automatically up to the point of target engagement via the data link, which could control both flight path and throttle
- Lightnings were fitted with two Firestreak IR missiles initially, with Red Top missiles later: the latter could engage head on, rather than only from behind.
- The RAP, the central control system, the Data Link, and the Lightnings with their Air-to-Air missiles together constituted the Interception System.
- The whole formed an enormous "sensors-processors-effectors" system

In the event, the threat never materialized, perhaps because it did not exist, or perhaps because the UK made it clear that it was potentially able to defend itself, while keeping the details of that defence under wraps.

Linesman evolved into Improved UKAD Ground Environment (IUKADGE), followed by a number of command and control systems as the Cold War cooled down.

Meanwhile, in parallel, the UK had developed a progression of fighter interceptors. After the Hurricane and the Spitfire came the Meteor and the Vampire, the Hunter and the Javelin, then the first Total Weapon System aircraft, the stainless steel Lightning, After that came the Phantom, basically a US aircraft, followed by the Tornado Air Defence Variant, which became the Tornado FMk2. And, more recently, the Typhoon. Not to mention the TSR2…

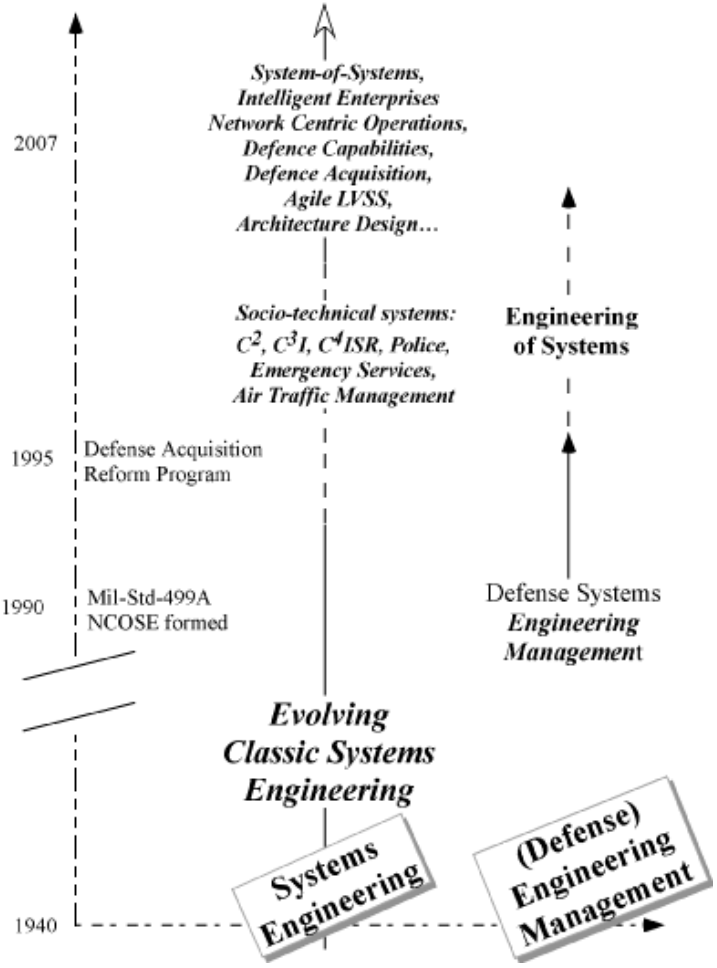

Figure 2. Evolution of SE and of EoS

Figure 1 shows US progress in parallel with that of the UK. Their experience with Gemini and Apollo gave them invaluable understanding of so-called

"green field" systems, i.e., where there had been no precursor. Apollo produced a succession of prototypes, one per mission, rather than a single solution system, e.g. Apollo 1 to 17. US Defense later encouraged competition for a new fighter. Following a seemingly expensive approach, two competing companies produced their solution aircraft to compete in a "fly-off." The winner was the F16, while the loser went on to become the F18, an equally successful fighter. So, not so expensive after all.

Another notable US Defense project, employing systems engineering on the grand scale, was the USN's Aegis. Developed by Lockheed Martin—"Aegis Combat System Engineering Agent"—over a 40-year period, Aegis is a sophisticated fleet-wide combat system. Major US aerospace & defense organizations tended to have their own systems engineering groups. In addition to Lockheed Martin, notable SE centres of excellence included TRW and Hughes. Such organizations regarded their systems engineering methods as a providing them with a competitive edge, and were generally coy about revealing their arcane methods. They did, however, publicize a number of "systems methods and tools" in the 1970s and 80s.

By the late 60s, early 70s, UK Systems Engineering had become a byword for "Complexity Management"…and sometimes for "gold-plating," too! Unlike the US, UK defence & aerospace systems engineering was undertaken by so-called "systems houses," which were independent of manufacturing companies, so as to ensure objectivity. The aim for systems houses was to tackle the challenging problem and to provide, as needed, a complete, bespoke solution to the problem: equipment, personnel, maintenance, simulators & trainers, publications, facilities, etc., etc. Leading UK systems houses were EASAMS, SDL and Logica: none of these undertook engineering; that was the realm of the defence and aerospace engineering companies.

The UK took part in Systems Design for President Reagan's "Star Wars"/Strategic Defense Initiative program in the 80s, which faced the Soviet MIRV[1] threat, an eerie reminder of the threat facing Linesman some 20 years earlier… *but* in some respects, UK SE was quite distinct from US SE, notably in its objectivity and commercial impartiality. US and UK SE were both World Class, but in their different ways!

Both countries recognized the end of the Cold War in the late 80s. The US scaled down its missile production, leaving many excellent systems engineers to find work in other fields, which they did. In the UK, times were lean for systems engineers too, and the UK government insisted on undertaking shared enterprises with other European countries, allegedly to save money—although, the process of sharing appeared to have been quite expensive…Perhaps we were trying to be "good Europeans," but our systems engineering skills became shared and diluted. The UK government also killed off the UK systems houses, choosing instead to work directly with the major defence & aerospace manufacturers, so saving money in the short term. In the process, they lost their principle source of expert, objective advice…and the UK lost its core systems engineering expertise…

Figure 2 shows what was happening to Systems Engineering: the US, in particular was trying to regulate it and formalize it. Mil-STD 499A was the flagship, which appeared at about the same time that NCOSE was formed, principally by US aerospace engineers. Mil-STD 499A and its successors were deemed " too expensive" by the then US Administration. Engineering of Systems (EoS) emerged as an apparent

[1] Multiple independently targetable re-entry vehicle

alternative to Systems Engineering, and it seemed to some observers that both Systems Engineering (in the US) and EoS (promoted by MIT, also in the US) were *de facto* Engineering Management. Mil-STD 499A, erroneously viewed by many as an SE "bible," was actually entitled "Engineering Management."

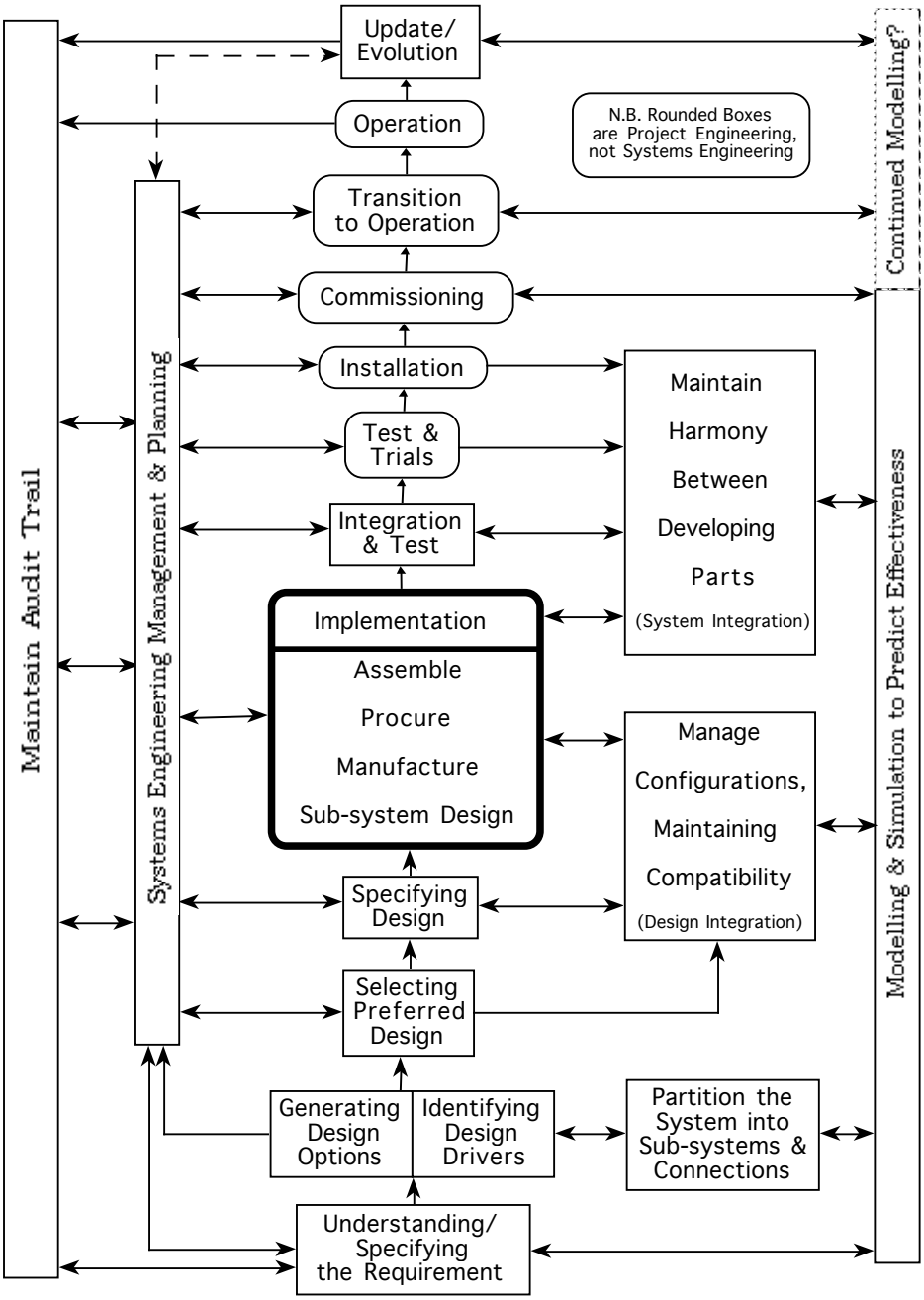

Figure 3. UK Systems Engineering Management Plan - c.1978

Meanwhile, UK Systems Engineering had been evolving. Figure 3 shows a typical UK SE management plan of the period[2], outlining both the systems engineering activities (rectangular boxes) and the engineering activities (rounded boxes), which were kept separate in line with UK Systems Engineering philosophy.

Meanwhile, on both sides of the Atlantic, interest grew in applying Systems Engineering to "human activity systems:" these were systems that contained a

[2] After an original design by Mike Smithums of Marconi Company

significant proportion of people, usually undertaking the intellectually challenging jobs that machines could not manage. So, Command and Control (essentially a human organizational role) was expanded into Command, Control, Communications and Intelligence (C3I), and further into Command, Control, Communications, Computers, Intelligence, Surveillance and Reconnaissance (C4ISR) in the US, and—not to be outdone—Command, Control, Communications, Computers, Intelligence, Surveillance, Target Acquisition and Reconnaissance (C4ISTAR) in the UK. But, they were all basically command and control, using whatever intelligence could be gleaned, so they were essentially Human Activity Systems (HASs) with technology tools.

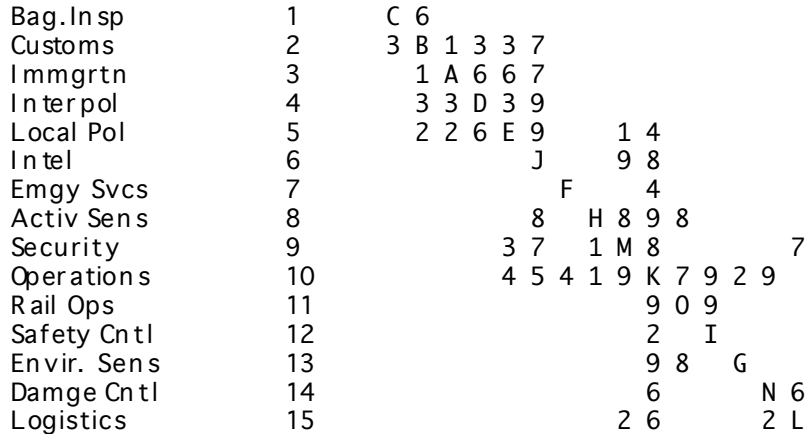

Figure 4. Architecture Design: Channel Tunnel Crisis Management, c.1988 Shows two principle, interacting systems, plus smaller attached systems: Customs, Immigration and Police at top; Crisis Management centred around Operations, at bottom (Unofficially developed at City University; not implemented due to perceived unnecessary cost…)

Figure 4 shows part of an unofficial architecture design for a Channel Tunnel Crisis Management System, c.1988, developed during a UK university systems engineering project;[3] this was, of course, a civilian Command & Control system. The figure is a printout from a computer assisted design tool, able to automatically configure an N^2 chart, using genetic algorithms, to reveal underlying architecture in a system. Robert J Lano originated the N^2 chart while working for TRW in the US in the 1970s, where its use was manual; by the 1980s, UK systems engineering was using its own automated version, able to tackle the architecture of large, complex systems in short order. Sharing holistic systems tools and methods between US and UK was alive and well during the 70s and 80s…

These included "Lano's Toolset:" N^2 Charts (TRW), Data State Design (IBM), R-Nets (Hughes) and Structured Analysis (functions and hierarchy). Robert Lano collected the other tools (along with his N^2 chart) to provide a complementary set, all of which worked at total system level, giving different views of any system, and which together enabled full systems design. At this time, US & UK Systems Engineering, although different, were both well defined, powerful systems-based disciplines, able to tackle the most complex of challenges.

Later, there were developments in Lean Volume Supply Systems, inspired by the success of Toyota and other Japanese manufacturers, who developed an altogether different approach to Systems Engineering, operating not at the product level, but at

[3] The project never went ahead; cost projections were considered too high.

the industry level. They optimized their industry using, amongst many strategies, the philosophy of *Kaizen*, or continuous improvement, contrasting strongly with the US "big-bang" philosophy of "get it right first time," which generally proved impracticable in complex situations.

Post 2000 AD, the notion of "system of systems" emerged, that is, the idea that one could make larger systems by bringing together smaller systems. In some respects this seemed rather obvious: any system consisted of subsystems, anyway, did it not? But in other ways, it was far from obvious. How many systems are needed to constitute a greater system? Are they all the same, or are they different, and if different, in what way? What might constitute a complete set of interacting systems to make a complete, greater whole/system?

These were questions that the inspirers of the Systems of Systems movement were coy about answering, but it was evident that the movement was a resurgence of the *systems* concept for Systems Engineering, and a counterbalance to the emerging philosophy of Engineering of Systems, which was clearly engineering, but which was equally coy about what were the "systems" it might engineer… were they *de facto* artefacts, or people systems, or something else?

Meanwhile, INCOSE seemed to be concerned, still, with the engineering of systems (EoS), rather than with systems engineering (SE). Had the founding fathers got the title wrong? Or had they so messed up the initial definitions of 'system' and 'systems engineering' that confusion was inevitable?

Defence agencies on both sides of the Pond saw some supposed advantage in adopting Systems Engineering in line with Defence/Defense Procurement, which made sense if it was actually Defence/Defense Engineering Management on the grand scale.

NCOSE: The Importance of Definitions at the Outset…

A reasonable definition of a System would appear to be *vital* at the outset, when forming a new society, organization, dedicated to SE: in the case of a new Council for Systems Engineering, it should put everyone 'on the same page,' and lead to a natural consequent understanding of what Systems, The Systems Approach, Systems Thinking, Systems Science and Systems Engineering were about…

NCOSE founding fathers, recognizing the need for NCOSE definitions at the outset, had come up with the following:

"A ***system*** is an interacting combination of elements
viewed with regard to function."

This was felt, particularly in the UK, to be an inadequate, even fallacious definition of 'system:' it seemed to omit some essential features:

- It was somewhat opaque; many people had trouble understanding what it meant:
    - It did not fit in with, and missed *fundamental* concepts from, conventional understanding which people had acknowledged for a generation, such as:
    - "System: complex *whole*; *organized* body of material or immaterial things; *set* of connected things or parts." *Pocket Oxford Dictionary 1946*

- It was at variance with other definitions by systems thinkers and theorists of the period.
- It precluded the Solar System, which does not appear to have any particular function, and so was no longer to be considered a system (sic).

In parallel, NCOSE defined Systems Engineering, admittedly with some difficulty:

"**Systems Engineering** is an **Engineering Discipline**
or,

Systems Engineering is *"**Engineering done properly**:"*
Jerry Lake, founding father of NCOSE

or,
Systems Engineering is Multidisciplinary Engineering (= **"Engineering.")**

These definitions, too, were devoid of any sensible concept of "System." As a direct result, NCOSE had set out on an Engineering Path, with no recognition of Systems, Systems Theory & Science, the Systems Approach, Systems Methods, Systems Thinking, etc.…

ADSPICE

Where are we now?

What is the state of contemporary Systems Engineering? E.g., are today's Systems Engineers capable of creating a modern version of Linesman? Or Aegis? Or *better?*

We are confused…well, most of us are!

To see how confused we are, one has only to look at the titles of papers presented at a a typical Systems Engineering conference to see how few are about SE, and how many are about some organization's current research into technology, project management or engineering management.

Not confused? Perhaps, then, we have not noticed some of the questions being asked…

- Is SE an engineering discipline, or something else?
- Is SE about Systems, or about technology?
  - Aren't systems simply man-made technologies?
  - Or does man-made technology = artifact, NOT system?
    - Artifact, like a flint axe, or Skylab…
    - …I.e., a tool to serve Man's purpose…?
  - Come to that, just what *is* a System, and what is *not* a system?
- Isn't Systems Engineering really *the same* as Engineering of Systems? If not, what is the difference?
- What is Soft Systems Engineering?
  - How do we go about it?
  - Isn't it about "messy" people systems—so not our business as engineers?

        - Or, as *Systems* Engineers, is it very much our business?
- Is SE applicable to Enterprises, Organizations, Industries?
- Just what *is* Systems Thinking and what *is* the Systems Approach?
- Is there a ***Theory of Systems/Systems Engineering?*** How should we apply it?
- What are ***Systems/SE Principles***; how do we apply them?
- Above all—why does SE appear to be so complicated, difficult and undefined?

And INCOSE at large is confused, too: factions have emerged attempting, unsuccessfully so far, to introduce systems and systems science into INCOSE's version of Systems Engineering (i.e., Multi-disciplinary Engineering).

So, just what is a System?

- The idea of "system" is of an ***organized, whole something, complete***.
    - Nature makes organized wholes—never without organization, never incomplete.
        - Solar System, star clusters, biosphere, cultures, weather, human cells—almost everything natural
    - Man-made systems are essentially the same idea:
        - "people-organized/manmade wholes…"
        - Whole aircraft, whole robots, whole organizations, whole processes, whole books, whole SkyLab…
        - Whence (w)holism and (w)holistic…

Self-Organizing Systems

The Universe is full of self-organizing systems, which arrange themselves into so-called ***Levels of Organization/Integration***:

- Super-galaxies
    - Particles form dust clouds,
    - dust clouds form into groups of clouds,
    - groups of clouds condense out into stars,
    - stars group into star clusters,
    - star clusters group into galaxies,
    - galaxies group into super galaxies…
- Ecosystems
    - Groups of interacting communities (flora and fauna) and environmental factors
- The Sun

- Three concentric shells, transferring energy from the core to the Sun's surface and beyond.

- You and me…

We humans are one of the most complex self-organizing systems on the planet. We comprise a complete set of interacting organ systems, as shown in Figure 5. These organ systems form a complementary set, i.e., a balancing, harmonizing set. While there are feedback loops in the body, it is also true to say that the body attains homeostasis (dynamic stability) by the counter balancing effects of complementary subsystems producing opposing effects (e.g. agonist and antagonist).

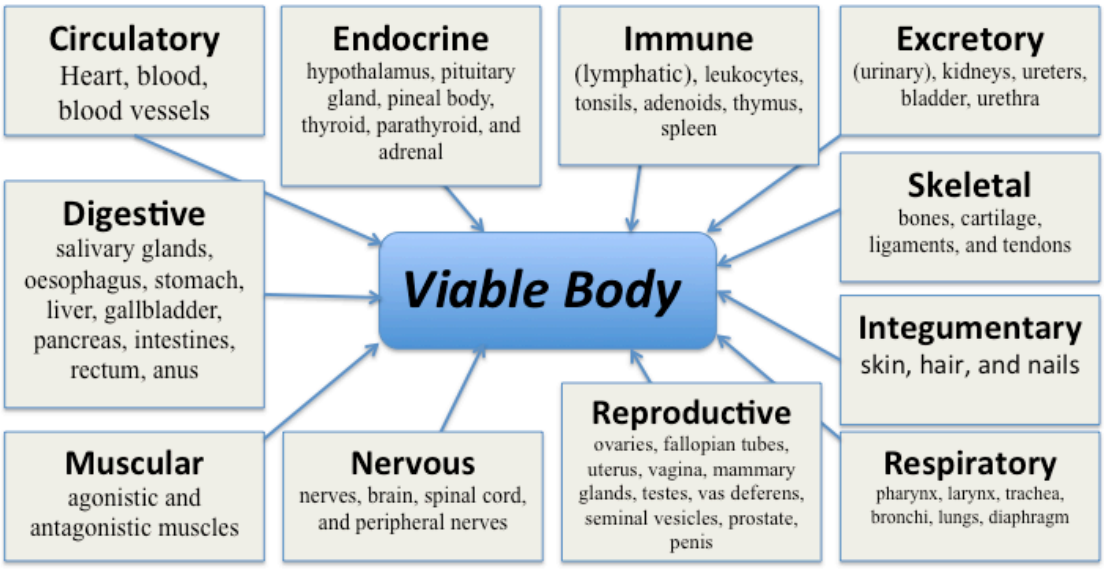

Figure 5. Organ Systems of the Human Body

Happily, not all systems are as complex as our human bodies, but the body can teach us something that biologists and anatomists found out centuries ago: there is a pattern in complex systems.

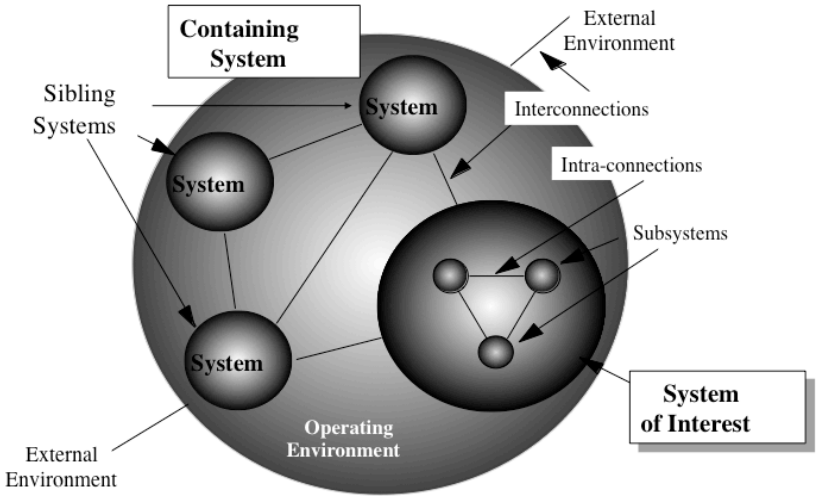

Figure 6. Hitchins' Poached Egg: A General Representation of any System

The figure shows a conceptual system-of-interest both as part of a network and in a hierarchy

That broad and general pattern is shown in Figure 6, which can be taken to represent just about any system, from a nematode, through humans with our organ systems, via Skylab and the Solar System, to our Galaxy and beyond. A System-of Interest (SOI) is shown at right, containing three intra-acting subsystems. The SOI is also shown interacting, directly or indirectly, with three Sibling systems within an Operating Environment, which effectively consists of those Siblings. All of the Siblings exist within a Containing System, which itself interacts with other, similar Containing Systems—not shown but indicated by the connections to External Environment.

The numbers of subsystems and sibling systems is indicative only, of course: were this Poached Egg showing the Human Body, then there would be some 11 or 12 organ systems within the SOI, not just three. And, at the risk of complicating things, we would be able to "dive down" into each of those organ systems to reveal the interacting organs inside.

Notice that we have said nothing in respect of Figure 6 about the natures of the various parts: this is simply a paradigmatic description of simultaneous networking and hierarchy that goes to describe the concept "system."

Levels of Organization/Integration

Moving on from the notion of Self-Organizing Systems and our Poached Egg figure, consider so-called *Levels of Organization/Integration*. Figure 7 shows, at left, conventional Levels of Organization/Integration from traditional Biology/Anatomy, then a corresponding hierarchy for Man-made Systems, and finally at the right, corresponding variants of Systems Engineering. The vertical axis is one of increasing complexity for all three hierarchies/columns.

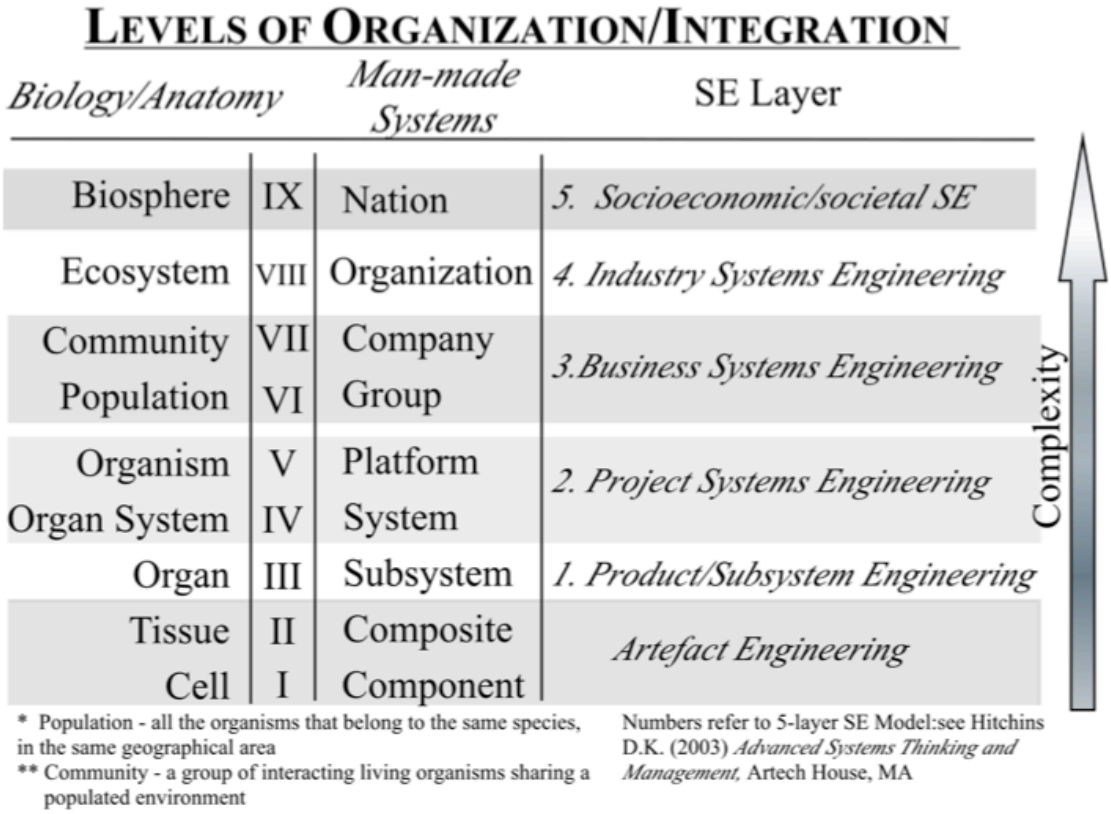

Figure 7. Levels of Organization/Integration—Correspondence Chart

The human cell is the smallest element that can be said to be alive—bottom left. Human tissues are made from the emergent properties of groups of differing human cells. Organs are made from the emergent properties of groups of differing tissues. Organ Systems are made from the emergent properties of groups of differing organs. And the complete organism is made, as we saw in Figure 5, from the many interacting organ systems. As Figure 7 shows, we can continue with successive groupings through populations of many organisms, communities of many populations, ecosystems of many communities and the biosphere of many ecosystems. All of this is conventional Biology/Anatomy/ Ecology.

As the central panel shows, it is possible to draw a very direct, and valuable, metaphor with man-made systems, by observing the correspondence between Organ Systems in the organism and Systems in the platform, which might be an automobile, an aeroplane, a ship, an enterprise, etc. Similarly, there is a correspondence between the organism and the platform, each autonomous and effectively carrying or containing their respective organ systems/systems.

Following this correspondence, we find the equivalent of a cell to be an active component—centre column, bottom. A composite is made from the emergent properties of differing interactive components; subsystems from the emergent properties of differing interactive composites; systems from the emergent properties of differing interactive subsystems; and, platforms from the emergent properties of differing interactive systems. We can continue upwards as shown in the centre column, to Group, Company, Organization and Nation…

The right hand column corresponds also, showing the different "flavours" of Systems Engineering as Systems Complexity mounts. Japan, for instance, has operated remarkably successfully at Systems Engineering Layer 4, Industrial Systems Engineering, compared with Levels 1 & 2 for the US and UK.

Defining a System

Using the insights from Figure 6 and Figure 7, we are now in a position to formulate a reasoned definition of a system:

A system is an open set of complementary, interacting parts, with properties, capabilities and behaviours emerging both from the parts (organ systems, subsystems) and from their mutual interactions to create an integrated, unified whole, existing in, and interacting with, an environment comprising other interacting systems.

To expand the definition:

- *Systems are wholes, complete.*
- *Systems have internal organization, with a full complement of interacting subsystem parts, also having the characteristics of systems*
- *Systems exhibit properties, capabilities and behaviours (emergence) that are not exclusively attributable to any of the subsystem parts, and which may not even be of interest at subsystem level*
- *Systems have an internal environment; the environment for each subsystem is the sum of all the other subsystems with which it interacts, directly or indirectly.*

- *Systems exist within an environment; the environment for a system is the sum of all the other systems with which it interacts, directly or indirectly*
- *Systems and their subsystems are Open, i.e., they exchange energy, information and substance with other systems, AND they adapt to the exchange.*

N.B. No mention is made, and none is needed, of *technology*, or *people*, or *enterprise*.

Whence Systems Engineering: "Making Wholes by Integrating the Complete Set of Subsystems." It really ought to be that simple! But, first, establish your subsystems…

So, what is the *Essence* of Systems Engineering?

The following sequence of actions presumes that Systems Engineering is regarded as a problem-solving paradigm: then, the *essence* of Systems Engineering may be envisaged in:

1. *Choosing (conceiving, designing, selecting) the Right Parts,*
2. *…bringing them together to interact in the Right Way,*
3. *and in Orchestrating those Interactions to create requisite Properties and Behaviours of the Whole,*
4. *…such that it performs with optimum effectiveness in its operational environment, (i.e. interacting with other systems),*
5. *…so solving the problem that prompted its creation.*

Note how "systems engineering" flows directly from the definition of "system"—as it should.

Prospice

…where are we going: INCOSE UK that is.

First, and before looking ahead, we should perhaps reflect on what has gone before. The UK was pre-eminent in Systems Engineering from the 1940s onwards, long before NCOSE and INCOSE. We have, in the past, shown excellent knowledge, understanding and practice of Systems, Systems Thinking, Systems Science and Systems Engineering. If this exceedingly powerful Philosophy and Practice are not to be lost, then we in the UK may have to show the way, *i.e. take the lead:*

- Recognize and establish Systems Engineering as a distinct discipline, with its, own science, principles, theory and practice:
  - Foster Systems Research and the development of Applied Systems Science.
  - Teach Systems Thinking in schools; teach Systems Engineering to Undergrads/Postgrads.
    - Develop Curricula; become the UK-wide authority for Curriculum Accreditation.
  - Establish a panel of "expert witnesses" for Industry, Government and the Media
- Establish a (generic?) Systems Methodology

- Folks need to know how to go about Systems Engineering: its not rocket science!

- Foster improved Systems Methods[4] and Tools
  - Including Problem Solving, System Dynamics, Purposing, CLMs, ISM, N2 Charts, and Simulation of "the dynamic whole in its interactive environment."
  - Purposeful architecture design, self-organized criticality/edge of chaos in design…
  - Develop a Systems Language, such that systems engineers can communicate sensibly with each other
- Understand, and evolve, the relationship between Engineering, Project Management and Systems Engineering
  - they really are NOT the same thing…
  - …but, each needs the others
- Get to Grips with Human Behaviour (psychology, behavioural science, social anthropology),
  - Human Activity Systems, Organizations, Businesses, Industries, Societal Systems, cultures, even political systems
- Get to Grips with Chaos, Edge-of-Chaos Operations, Self-Organized Criticality and Entropic Cycling in systems of all kinds: it is the new norm!
  - Chaos: ever present, exploitable. S-OC: common as systems succeed and start to exceed their capacity, but also exploitable. Entropic Cycling in all open, hierarchical interacting systems

Systems Methodology

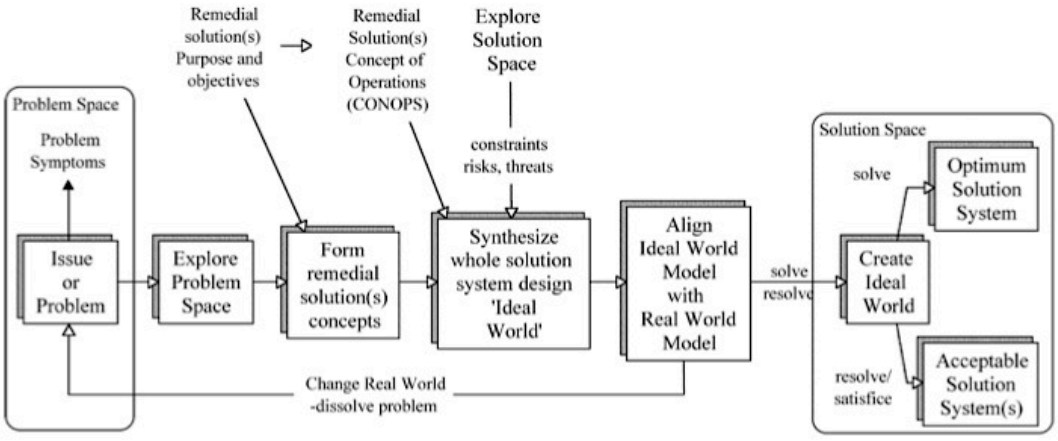

Figure 8. Generic Systems Methodology—Outline Concept

N.B. This outline is applicable, not only to the initial system in design, but also to the delivered system in operation as the problem/issue morphs, as the environment, risks and threats change, and as the system is used in ways not anticipated by, probably not even knowable by, the designers

[4] A System Method is system-theoretic, *type*-independent, *scale*-independent & *technology* independent. Causal Loop Models and N^2 Charts are examples of Systems Methods

There are several ways in which a generic systems methodology, or systems engineering methodology, might be presented. First, if Systems Engineering is consistent with the problem-solving paradigm, there should be some means of addressing complex problems and issues

Figure 8 shows a Systems Engineering Methodology high-level (i.e. abstract) concept, with the potential to "solve, resolve or dissolve" the problem, which is presented in the left hand box. To solve is to find a precise, optimum solution; to resolve is to find an acceptable solution, one that is "good enough"; to dissolve a problem is to change the situation in which the problem is generated, or perceived, such that the problem no longer exists (a.k.a. Kobayashi Maru). The concept embraces the notion of an Ideal World Model, one in which the problem or issue no longer exists. The objective of SE, then, is to create that Ideal World, using as its stimulus the differences between the Ideal and Real World Models.

Figure 9 shows a simple model of one formal Systems Engineering Problem-solving Method[5], the Rigorous Soft Method (RSM). An "Issue" presents at the top, and the problem solver(s) follow the sequence clockwise, using symptoms of the Issue as a means of delving into the issue "internals," and so identifying implicit systems that are in imbalance within the body of the problem. (This is reminiscent of the manner in which a doctor may use symptoms of disease or disturbance to identify which organs may be responsible.) The RSM verifies that the proposed solution to the problem, if implemented, would indeed resolve all symptoms; if not, some or all of the procedure must be repeated.

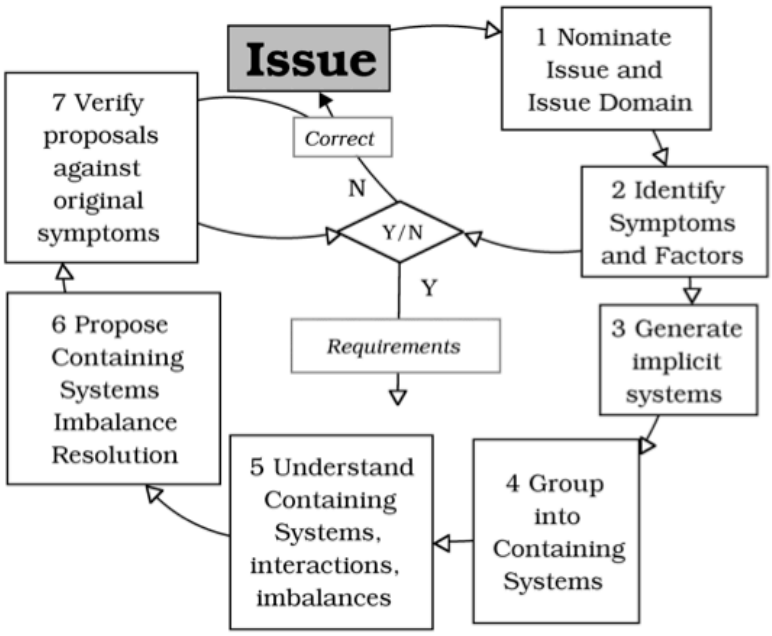

Figure 9. The Icon of the Rigorous Soft Methodology (RSM)

Systems Engineering Principles

It is not always clear what is meant by Systems Engineering principles. However there are four fundamental principles that should focus SE attention and actions:

[5] Peter Checkland's Soft Systems Methodology is also a systems problem-solving methodology, for addressing so-called "messy" human activity and organizational system problems

1. **Holism**: systems (physical, biological, chemical, social, economic, mental, linguistic, etc.) and their properties should be viewed as wholes, not as collections of parts. Systems function as wholes: their functioning cannot be fully understood solely in terms of their component parts
    a. It should be axiomatic, then, that systems engineers address the whole system, and never any parts in isolation, throughout their creative processes from beginning to end.
2. **Organicism**: systems (like organisms) have parts that function in relation to the whole to which they belong.
    a. So, in addressing the whole, one may do so at the level of all the interacting subsystems constituting that whole
3. **Synthesis**: combining two or more entities to make something new
4. **Emergence**: Higher-level properties emerge out of lower level properties, to which they cannot be reduced.
    a. It is not possible to predict simply from our knowledge of lower level properties what form the higher ones will take.
    b. Nor is it possible from our knowledge of higher-level properties to know the lower level properties of parts within the organized whole.

N.B. These four, together and separately, propose that Systems, the Systems Approach, Systems Thinking and Systems Engineering are inconsistent with reduction (e.g. functional decomposition) as employed by engineers and hence Engineering of Systems (EoS).

These principles set Systems Engineering apart as unique, and distinct from other disciplines. They also engender the ability to accommodate great complexity, to be innovative and creative, and to address an exceedingly wide range of issues and problems.

The Systems Domain

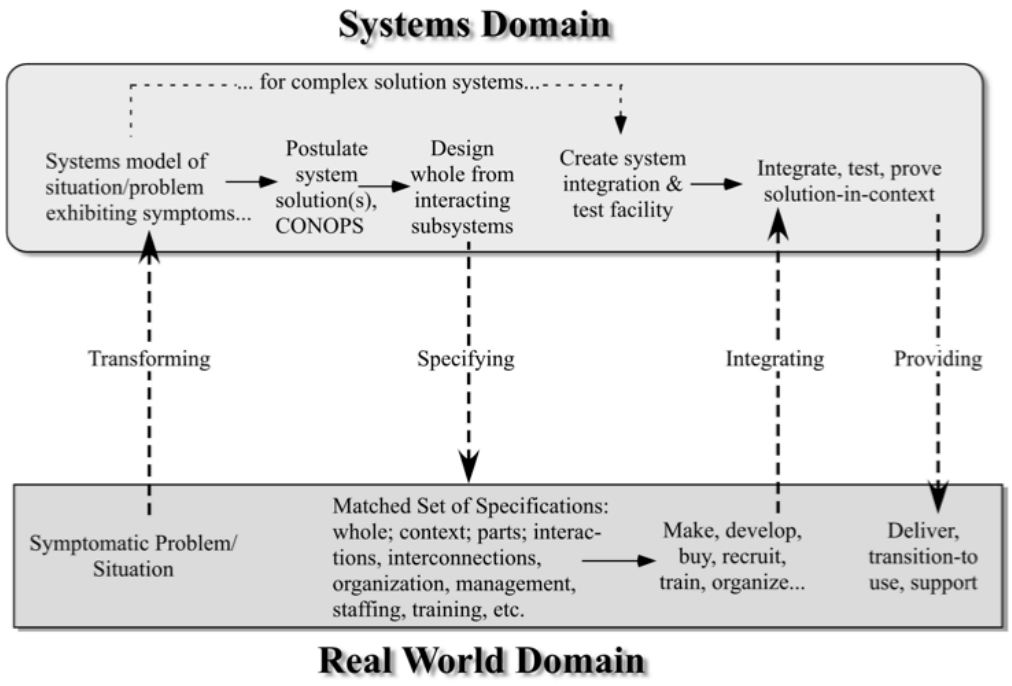

Figure 10. Systems Domain Vs. Real World Domain

Figure 10 shows schematically how, for traditional systems-based systems engineering, the Real World Domain, at bottom, differs from, and interchanges with, the Systems Domain where Systems Engineers practice, at top; making the two complementary and cooperative. The Symptomatic Problem/Situation clearly arises in the real world, bottom left, but is soon transformed into a systems model of the problem, as suggested in Figure 10. Systems Design seeks to create the Ideal World, i.e., one in which the problem no longer arises. Following the arrows shows how the activities switch between the two domains subsequently, with engineers concerned with making—or buying-in—the many and various parts of the solution system. Finally, top right, the solution system is integrated, tested, proved and, bottom right, delivered to the real world.

Activities in the Systems Domain largely follow the Systems Methodology of Figure 8. Note that, for complex solution systems, there will be a need to create a systems integration and test (I&T) facility, in which to prove the created solution system. Note, too, that this separation of systems from engineering applies also after the delivered system has become operational and is facing new problems changing environments, is being used in ways not anticipated by the original designers, is behaving counter-intuitively, etc., etc.

Conclusion

Systems-based Systems Engineering is struggling to survive in INCOSE at large, which has dedicated itself instead to engineering of systems! Valiant attempts by various individuals to introduce Systems Engineering into INCOSE are not, so far, meeting with material success. There is little agreement on even the most fundamental of ideas, such as those espoused earlier, of defining a ‘system’ (sic).

Certainly, classic Systems Engineering, as practiced so successfully in the 20th Century by both the US and the UK, is in danger of being swamped—within INCOSE, at least—by Engineering of Systems and Engineering Management advocates, to the detriment of both UK industry and UK society.

Meanwhile systems in the real world are becoming inexorably more complex, and inclined to non-linear behaviour: social systems, media systems, weapon systems, C^2 systems, energy systems, global systems, weather systems, systems of systems, transport systems, financial systems, health systems, conflict systems…etc., etc.

And the real world is trying to understand and accommodate the non-linear behaviour of non-Gaussian networks of systems, such as national IT systems, transport systems, global financial systems, etc., which seem instead to be converging on biological systems, and behaving according to power laws (so-called “fat tails”) making it difficult/impossible to predict systems behaviour, and to manage risks accordingly. Examples of this “power law” behaviour (sometimes called “weak chaos”) include distances between cars on the freeway/motorway, thermal noise in conductors, size Vs. frequency patterns of meteors, earthquakes and volcanic eruptions, stock exchange price fluctuations, climate systems, crime patterns, and many many more. All of these, and many more, are the stuff of future Systems Engineering, which we in INCOSE should be getting to grips with today.

Instead of hiding behind a shield of out-dated, linear engineering, SE *should* be facing up to challenge of conceiving/creating/operating/adapting/enhancing today's *and tomorrow's* complex, large scale systems and networks of systems, which are significantly more challenging that those of the 50s—80s. INCOSE is falling/has fallen behind the curve…

INCOSE UK has the knowledge, ability, experience and background to restore Systems Engineering to its former state—and to be much *better,* as it needs to be to face the challenges ahead: if not by persuading INCOSE central, then perhaps within INCOSE UK, so that we, at least, need not forgo our UK heritage. But, does it have the energy, will and resources?

Or, has the Dark Side seduced us already?

18th November 2014 (Derek Hitchins)