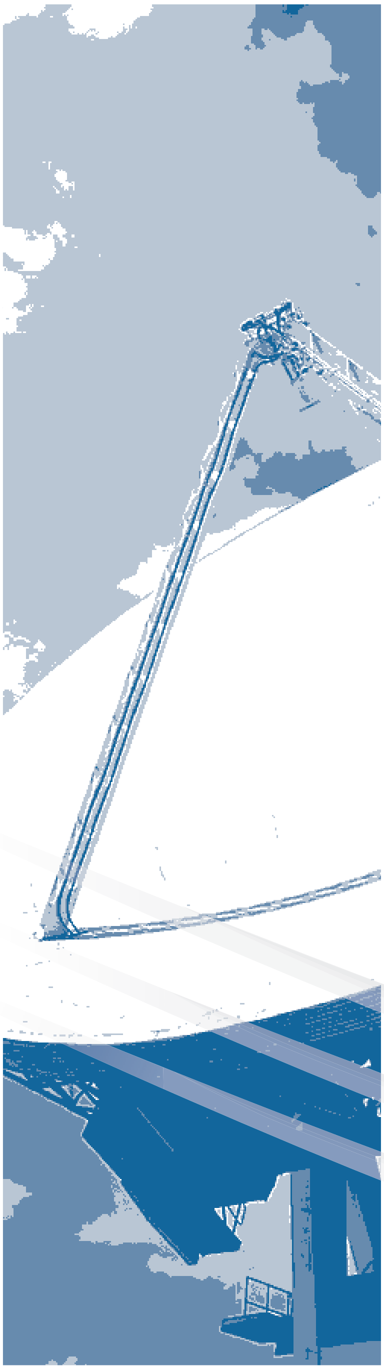
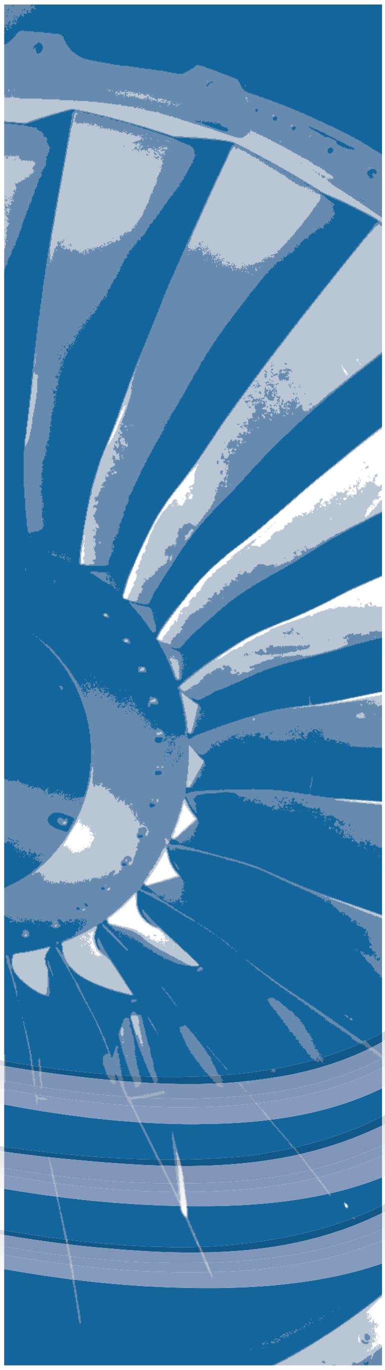
INCOSE UK

SEASON Report 2009

Systems Engineering Annual State of the Nation





INCOSE UK
SEASON Report 2009

(Systems Engineering Annual State of the Nation)

Prepared by the SEASON Working Group
Published by the UK Chapter of the International Council on Systems Engineering

Distribution

This report will be available to INCOSE UK and UKAB membership from 1 February 2009 as an exclusive member benefit.
It will be available on the INCOSE UK public web site on or after 1 July 2009.

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Contents

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This report was compiled by Mr Hillary Sillitto, Past President of INCOSE UK, with contributions and peer review from: Ady James; Paul Davies; Jo Stoves; Pete Lister; Patrick Godfrey; John Hooper; David Oxenham; Dave Hawken; Ian Bowbrick, RAEng; Derek Hitchins; Phil John; Ayman Al-Fatatry; Paul King; Stuart Arnold; Mike Purshouse; Engineering Technology Board; Institute of Physics; INCOSE UK Board; INCOSE UK Advisory Board.

Executive Summary

Systems Engineering is a key skill required to develop and operate the complex systems on which modern society increasingly depends. Manufactured products are increasingly becoming low cost high quality commodities; the UK's competitiveness and prosperity depend on its ability to add value through systems integration. Yet many high profile projects in both the public and private sectors fail through lack of the holistic through-life perspective that Systems Engineering provides. [1]

The report assesses the health and fitness of Systems Engineering in the UK and comes to **five key conclusions**, which are listed below; makes some additional **key observations**; and recommends **three axes of development** for the UK Systems Engineering community to address the conclusions. The key conclusions are:

1. Systems Engineering is important to the economy – both to grow high value systems integration business and to mitigate the huge risks we can run when decision makers do not understand the systemic risks in their domain (see the current economic crisis).
2. There is evidence that the UK is getting better in Systems Engineering and Systems Thinking but others are getting better faster.
3. There is a need to improve the standing, recognition and reputation of Systems Engineering in academia.
4. There appears to be a large and growing mismatch between education provision and industrial and government demand for Systems Engineering and Systems Thinking.
5. We need to get a better understanding of how systems skills develop and are deployed in the "real" economy, this requires us to define and measure Systems Engineering skills and competencies and how they fit with other professions and skill sets.

There is room for improvement in the way we in the UK develop our Systems Engineering knowledge, capability and capacity and convert these into business outcomes - and there is a strong imperative to do so to keep our economy competitive. Systems Engineering is integrative and cross-disciplinary in nature: there is a need for more systems awareness across the whole engineering, project management and commercial community, and a more consistent professional identity for systems engineers and systems-trained professionals.
Some additional **key observations** are:

> We in the UK need to improve the way we approach "systems" and complexity. Systems Engineering is part of the solution, taking a holistic perspective which is a key enabler for this improvement.

> National capability, competence, effectiveness and capacity in Systems Engineering are difficult to assess. However there is evidence of an increase in awareness, understanding and application of Systems Engineering in the UK.

> The Government is showing evident commitment to a better systems approach. It will take time, sustained effort and continued commitment to achieve the desired across-the-board improvement in systems competence and delivery performance.

> There appears to be a large gap between the number of Systems Engineering practitioners produced by universities and the number that industry and government need. This gap is presumably filled to an unknown level of adequacy by in-house and commercially available training courses and by individuals' continuous personal development, for example through participation in INCOSE.

> There is a demand to define and police standards of both Systems Engineering professionalism and course content and effectiveness.

> Many competent and effective systems engineers come from outside engineering. Their skills must be exploited and their needs recognised as we set the professionalisation and education agendas.

The report's authors also recommend **three key axes of development** that can be implemented by the Systems Engineering community to address the three of the five key conclusions that the systems community can shape directly. These recommended actions are:

1. Improve the Academic profile of Systems Engineering and Systems Thinking by setting out an agreed, intellectually rigorous foundation for the discipline.
2. Seek to establish a Systems Knowledge Transfer Network with as wide as possible stakeholder enagement to get better visibility of what's going on in and around Systems Engineering.
3. Establish a Professionalisation agenda to get better visibility of and provide better support for peoples' skills and development.

[1] It is not our intention in this report to dwell on the negative or to direct specific criticism. However we were challenged to substantiate this assertion. Important classes of system failure include these three:
> time and cost over-runs due to not understanding or recognising the nature of the problem;
> failure of the system to operate profitably and dependably in service;
> failure of the system to achieve its intended purpose.
We cite as evidence one well publicised example of each these three categories: the Scottish Parliament building cost 10 times the original budget; the Channel Tunnel was expensively refinanced soon after opening; Chinook helicopters intended for Special Forces had to be reconfigured for general duties.

Introduction

Background to the SEASON Report

The "SEASON REPORT" aims to establish a national baseline of the UK's Systems Engineering capability. It was prepared by a working group of the UK Chapter of INCOSE, the International Council On Systems Engineering, with the support of its corporate members, the UK Advisory Board (UKAB). It is the first such effort and will be updated annually, or periodically as appropriate, and augmented from time to time by topical reports.

It provides an evidence base that can be used to inform decision makers in Government, Industry and Academia so that they can make decisions leading to actions that will improve the UK's national Systems Engineering capability. This will in turn improve the UK's ability to acquire and develop complex systems and manage them through life, and to participate effectively in international Systems Engineering endeavours, hence maintaining the UK's economic and social viability and its international competitiveness as a value-added system and service integrator in the global supply chain.

The "SEASON REPORT" was prepared through an inclusive process engaging corporate and individual members of INCOSE UK and national and international experts in Systems Engineering. It draws also on a wide range of sources both public and unpublished. Key editorial contributions and references are acknowledged in footnotes to the text.

What is INCOSE? [2]

INCOSE, the International Society for Systems Engineering, was founded in the US in 1991, and went international in 1994. It runs an International Symposium every year, operates through local chapters and working groups, and publishes a range of technical products for practising systems engineers, and a peer reviewed academic journal [3]. It has about 50 Chapters, of which about 20 are outside the USA, and approximately 7000 individual and 50 corporate members (the latter including UK MOD and several other UK organisations). Its useful website is at www.incose.org.

INCOSE's UK Chapter was founded in 1994, established itself as an independent UK legal entity (INCOSE UK Ltd [4]) in 1998, and had approximately 750 members when it closed its books for 2007-8. It runs 2 annual conferences, and has an active local group network with regular meetings in various parts of the country. It has over 20 corporate members from industry, academia and government. Its events programme and a wide range of UK-focused information, including 1-page guides on various aspects of Systems Engineering, can be found on its website at www.incoseonline.org.uk

The benefits engagement with INCOSE provide to the UK include access to a dynamic international community of systems engineers, the right to use a valuable body of knowledge, and influence on the Systems Engineering agenda for research, education, standards, and application.

Invitation to participate

INCOSE UK is committed to an inclusive approach working with a wide range of stakeholders to improve the condition of Systems Engineering in the UK.

This is the first version of this document. It will be updated. We want it to be inclusive and accurate: we apologise in advance for the inevitable omissions, errors and approximations. We invite all UK organisations with an interest in Systems Engineering and the systems approach to join with us to improve the accuracy, completeness and utility of future versions.

If you want to get in touch, offer help, provide details of your activities, and particularly offer examples of how you apply Systems Engineering in your industry, what courses you run, etc, please contact season@incose.org

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POSTSCRIPT June 2009.

The main work of compiling the report was done in the summer and autumn of 2008. As we go to print in June 2009, the near-collapse of the world's financial system and the agenda set by the opening days of the Obama presidency confirm our evidence and reinforce our conclusions. The "real economy" needs systems skills as never before to develop viable systems and services which create real, enduring and environmentally sustainable value for the economy.

The autumn's EPSRC funding decisions substantially changed the landscape of UK Industrial Doctorate programmes in systems topics. The loss of some useful programmes emphasises the need for the systems community to make its case better, with consistency and intellectual rigour and with full regard to the economic benefit.

[2] INCOSE (Pronounced "In-cosy") – International Council On Systems Engineering
[3] Systems Engineering, Wylie
[4] INCOSE UK Limited is registered in England under no. 3641046. Registered address: 3 Trinity Road, Folkestone, CT20 2RQ

Systems Engineering in the UK

What is a system?

A system is "a group of elements interacting with each other and their environment for a purpose". Further, "A system is a set of parts which, when combined, have qualities that are not present in any of the parts themselves." Those qualities are the "emergent properties" of the system. [5] Many "systems" are much more than engineered artefacts: the "elements" or "parts" of a system may include, if appropriate, people, processes, information, organisations and services as well as software, hardware and complex products.

Two extremely different kinds of system, the "London underground system" and a digital camera, have (at least) one thing in common: they provide their user with a "capability" – the ability to do something that produces a useful result and achieves a valued outcome – that is not provided by the elements of the system acting independently.

There is no discontinuous step from "system" to "not a system". Indeed it is generally accepted that "one man's system is another's subsystem"; and there is no discontinuous jump, but rather a continuum of increasing complexity, as we move from "product development" to "systems engineering". This line of argument is expanded in the next section.

What is Systems Engineering?

Systems Engineering is a key skill for the successful delivery of complex systems and services, and as such complements programme management and "traditional" engineering. First codified during the 1950s for the US space and ICBM programmes, and described in a seminal text by Hall in 1962 [6], it offers a dependable way to develop high integrity solutions to novel and complex problems. Systems Engineering has been successfully applied to a wide range of problem domains, and is now seen as a key enabler for success in our increasingly complex and rapidly changing world.

When dealing with complex problems and complex systems, Systems Engineering seeks to "do things right" (to follow a disciplined, justifiable, well-governed process) and "to do the right things" (to solve the right problem and achieve the desired outcomes).

INCOSE's website states that *"Systems Engineering is an interdisciplinary approach and means to enable the realization of successful systems. It focuses on defining customer needs [7]and required functionality early in the development cycle, documenting requirements, then proceeding with design synthesis and system validation while considering the complete problem. - - 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."*

Systems Engineering uses principles of Systems Thinking that are also applied in areas as diverse as social science and environmental management. "Systems Thinking" is a way of tackling complex problems. It complements scientific thinking by addressing holism, [8] emergence and intentionality.

Systems Engineering complements other branches of engineering and management by focusing from the earliest part of, and throughout, the system lifecycle on:

> Operational purpose, context, value, and usage
> Whole system/whole service, whole life
> Stakeholders and the "Human in the system"
> Mastering complexity and the consequential risks and opportunities
> Emergent properties

Emergent properties deserve a special mention: they are "properties of the whole not attributable to any one of the parts". They arise when system elements interact with each other and their environment, and only exist when individual components of a system are connected together so that they can interact. They bring the threat of unintended consequences, a major cause of embarrassing system and project failures, but also the opportunity to make "the whole greater than the sum of the parts". Skilled systems engineers create higher value for less cost, by using the emergent properties of the interactions between components to create the desired system behaviour.

Systems Engineering is closely focused on reducing the risk of time and cost over-runs and of shortcomings in satisfying stakeholder requirements and constraints.

[5] "Creating systems that work – Royal Academy of Engineering, 2007
[6] Arthur David Hall III, 1962, A Methodology of Systems Engineering
[7] Stakeholder and Purpose are key elements of the "UK flavour" of systems engineering. The definition might be re-expressed "customer **and stakeholder** needs **and purpose**, and required functionality- - - "
[8] Holism: considering the "whole" and the properties of the whole system, in contrast to the "reductionist" approach often used in scientific and engineering endeavour. There is growing recognition that "Complex systems are not decomposable", that reductionism does not address the complexities of modern integrated man-made, natural and socio-technical systems.

Application of Systems Engineering

Systems Engineering is applied within established domains (engineering or other), across domains, and to large scale and unprecedented problems. It is both part of, and outside, traditional engineering. [9] Many people do Systems Engineering without calling it that – particularly in organisations with effective integrated product development processes and design methodologies. INCOSE has grouped applications areas of interest to its members as:

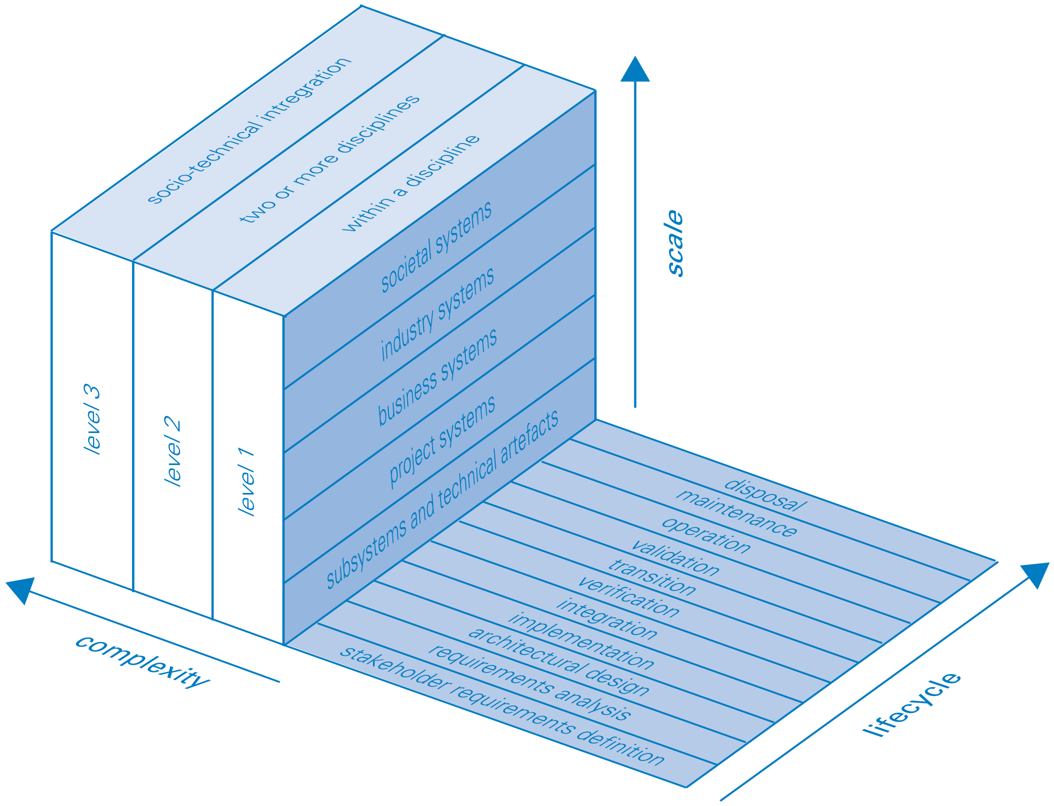
> Aerospace and defence
> Market driven products
> Emerging technologies
> Enterprise
> Information systems
> Infrastructure
> Public Interest
> Transportation

Each domain tends to apply Systems Engineering in a different way depending on the dominant business models, constraints and systemic risks of the domain. In the UK, systems engineers work in many sectors including rail, automotive, civil aviation, infrastructure, astronomy, space, IT and security sectors as well as Systems Engineering's traditional stronghold in the defence industry.

Systems Engineering has a broad scope and has proved difficult to bound. [10] It is useful to consider several distinct dimensions, which illustrate a number of the different – and as yet not fully reconciled - "worldviews" of Systems Engineering:

> A **complexity** dimension: the Royal Academy of Engineering report "Creating systems that work" [11] identifies three levels of Systems Engineering, proposed by Prof D Stupples:
  > 3: Concerned with complex socio technical systems integration
  > 2: Spanning two or more disciplines
  > 1: Within a single discipline

> A **scale** dimension: Five levels of systems, as defined by Prof Derek Hitchins: [12]
  > 5: Societal systems
  > 4: Industry systems
  > 3: Business systems
  > 2: Project systems
  > 1: Subsystems and technical artefacts



[9] This is a point of contention. Positions in the debate range from "Systems Engineering sits outside engineering" to "Systems Engineering is merely good engineering". Most organisations see it as complementary to "traditional" engineering. We seek to accommodate all views and allow the market to decide
[10] Eames, Smith and Cowper, "Confronting an identity crisis - How to brand systems engineering", Systems Engineering Volume 8, Issue 2, 2005
[11] Report on Integrated System Design: http://www.raeng.org.uk/education/vps/pdf/RAE_Systems_Report.pdf
[12] D.K Hitchins, Systems Engineering: a 21st century methodology, Wiley/Blackwell, Nov 2007

> A **lifecycle** dimension: The system lifecycle process framework defined by the ISO/IEC Standard 15288, "System Lifecycle Processes":

> Stakeholder Requirements Definition
> Requirements Analysis
> Architectural Design
> Implementation
> Integration
> Verification
> Transition
> Validation
> Operation
> Maintenance
> Disposal

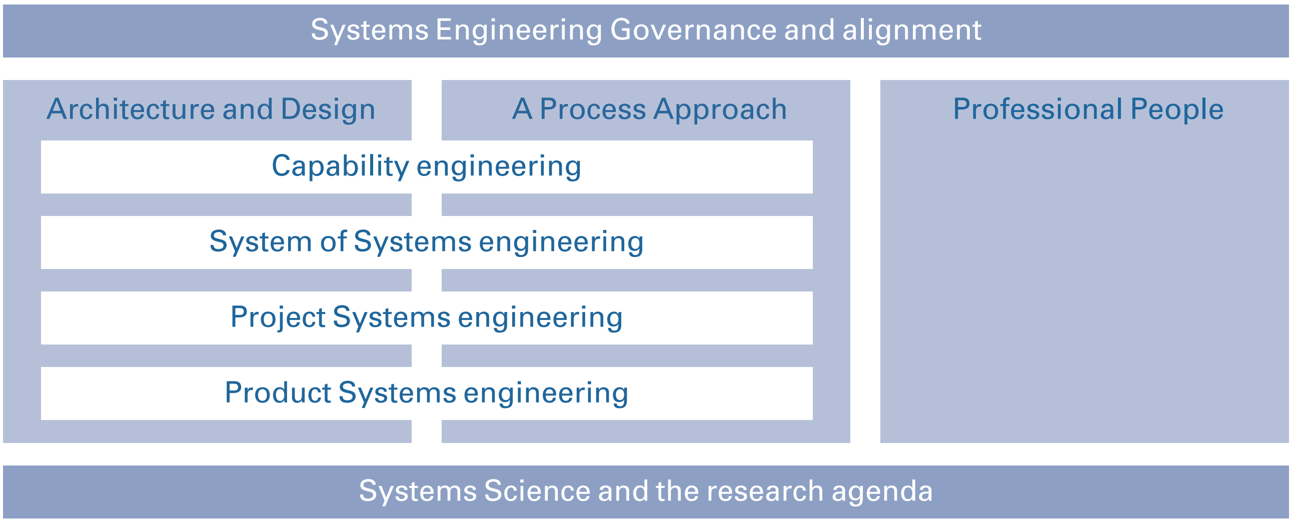
> An **organisational** dimension: Five pillars of Systems Engineering, adapted from the UK MOD Systems Engineering handbook:

> Governance and organisational alignment
> Architecture and design
> A process approach
> Professional systems people
> Systems science and practice

> MOD also identifies four levels of application of Systems Engineering within defence, broadly corresponding to Hitchins' first four levels:

> Defence Capability Engineering
> System of Systems Engineering
> Project Systems Engineering
> Product Systems Engineering (subsystems and equipment)

The lifecycles of "Capabilities" and "Systems of Systems" are more complex than, and different in nature from, those of products and project systems.



> The INCOSE UKAB Systems Engineering Competency Framework [13] identifies three fundamental areas of competency for systems engineers:

> Systems thinking - Systems Engineering within a context, understanding the system's environment and the containing "supersystem"
> the "doing" of Systems Engineering throughout the lifecycle – e.g. system architecture and design
> "managing" Systems Engineering – "a process approach"

Perspective

There are differing views on what Systems Engineering is, which confuses stakeholders. INCOSE UK aims to provide a framework within which to understand and manage the application and value of Systems Engineering across all application domains in the UK.

[13] Systems Engineering Competency Framework – INCOSE UK Advisory Board, 2005(Issue 1) and 2007 (Issue 2), available at www.incoseonline.org.uk

Trends and Indicators in Systems Engineering

There is a growing need and demand for Systems Engineering skills and knowledge, not fully satisfied by the supply side. Evidence for this assertion includes the following.

> In the last three years INCOSE UK membership has grown from a 10-year plateau of about 400 to over 700. The IET Systems Engineering network has seen similar growth.

> Corporate membership of INCOSE UK has increased from 8 organisations to 23 in the last three years.

> The ISO/IEC 15288 Systems Lifecycle Processes Standard was published in 2002.

> The Systems Engineering conference calendar has become congested. In the last three years it has become difficult when scheduling conferences on Systems Engineering and related subjects to avoid clashes with other conferences on similar subjects.

> MOD has committed to a Systems Engineering approach. The Defence Innovation Strategy, [14] published in autumn of 2007, identifies Smart Systems Engineering as one of the "5 pillars of innovation". A new policy paper from DE&S describes the MOD approach to "Implementing Systems Engineering in Defence". [15]

> Systems Engineering is applied increasingly and effectively in a wide range of other sectors including rail, infrastructure, civil aviation, automotive, telecoms and IT.

> Ten years ago three universities were considered to be active in Systems Engineering; now several are considered to be of high quality and around 40 offer courses in Systems Engineering or closely related subjects.

> Most major employers of systems engineers have vacancies for them, are launching skills development programmes in house and/or in conjunction with universities, and express some level of discontent with the current supply situation.

> At least 2/3 of the employers represented in INCOSE's UK Advisory Board` are actively recruiting Systems Engineers, and investing in in-house competency assessment and skills development programmes.

> The Royal Academy of Engineering has published a report identifying a serious risk of critical shortfalls in the UK's systems integration capability and is funding visiting professorships at over 20 universities in Systems-level and cross-disciplinary engineering. [16]

> A recent survey conducted by MOD indicates that there are of the order of 10,000 Systems Engineering jobs in about 20 major defence contractors in the UK. These jobs leverage about 10-20 times as many in those companies. It is reasonable to assume that these trends are replicated in the non-defence sectors that apply Systems Engineering.

> About 150 companies are registered as able to provide Systems Engineering and Systems Engineering services in the UK MOD's supplier database.

> Estimates of how these figures scale to the whole of the UK defence sector and to non-defence industry represented in INCOSE UK's membership allow us to generate an estimate of the overall importance of Systems Engineering and Systems Integration skills to the UK economy. [17]

> There is a gathering recognition of the need for Systems Engineering skills in infrastructure and manufacturing industries. Initially this took the form of introduction of tools like Lean Process, copied from the Japanese. Now it is recognised that this has to be embedded within a context of Systems Thinking to address the complexities of globalisation and sustainability.

> Several successful post-graduate Systems Engineering programmes have been launched.

> Other countries appear to be ahead of the UK in their commitment to Systems Engineering. For example the Netherlands requires Systems Engineering to be applied to infrastructure programmes, due to the risk and impact of unintended consequences if these programmes are not properly planned and integrated with the existing infrastructure.

Perspective

The trends are encouraging but there is a long way to go. The commitment in Government is welcome but will take time and sustained effort and commitment to become pervasive at all levels. Notwithstanding the encouraging progress in some universities, there are several fundamental issues about Systems Engineering in academia:

1. *Academic capacity to educate and train systems engineers is less than the apparent industry and government demand.*
2. *Only a few universities see Systems Engineering as a mainstream subject, and it is not recognised by many academics as a discipline worthy of academic study.*

[14] Defence Innovation Strategy, http://www.mod.uk/defenceinternet/aboutdefence/corporatepublications/scienceandtechnologypublications/sitdocuments/defenceinnovationstrategy.htm
[15] http://www.aof.mod.uk/aofcontent/tactical/engineering/downloads/se_implementingindefence.pdf
[16] See Annex 5
[17] See Annex 2 for an analysis of INCOSE UK membership, and Page 13 for "An estimate of the industrial significance of Systems Engineering"

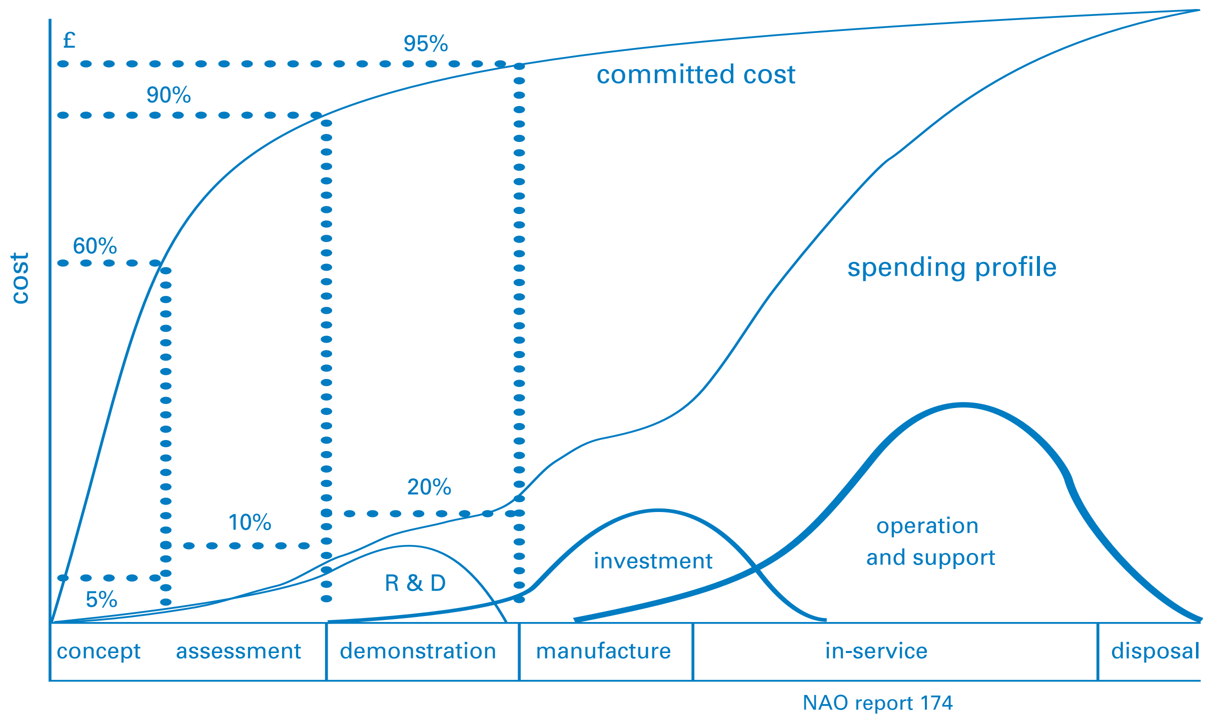
This appears to be because it is not a traditional engineering subject based on physical properties etc. Rather, Systems Engineering grew through industrial and government practices and has only recently been tackled by universities. This situation is not confined to the UK, but other countries are ahead of us in establishing the academic credentials of Systems Engineering, notably the US and Australia.

3. *A recognised academic foundation for the subject is not yet established and accepted. Academic approaches to Systems Engineering must be based on a sound foundation of enduring principles and systems science, while practitioners apply these principles and science within a domain and lifecycle context.*
4. *There is little consistency across the range of Systems Engineering that is taught in different universities.*
5. *Where Systems Engineering is taught "within a discipline" (Stupples level 1), this limitation is not always made clear to students – it may indeed not be clear to the staff.*

Realising the benefits from Systems Engineering

Systems Engineering needs to be done at the right time

Systems Engineering has greatest impact early in the lifecycle when change is still cheap. Typically in the development of large-scale complex systems, 60% of through-life cost has been committed (wittingly or otherwise) by the time 6% has been spent. Appropriate application of Systems Engineering reduces risk in unprecedented and challenging endeavours, so that extremely complex projects become possible (e.g. Eurofighter and the new Carriers), and "normal" complex projects can achieve purposeful outcomes at reduced cost and risk, with successful management of complexity, critical transitions and change.



source: Andy Worrall MOD UK

Systems Engineering must be done the right way

Up-front Systems Engineering effort must be applied wisely. If the future is uncertain and change is inevitable, we should not try to predict or constrain the future; rather we must understand the range of uncertainty and change, and architect the project and the system to have the flexibility to cope and adapt.

Systems Engineering is not just about system design: it is also about through life management of both the system and the enabling processes. Insufficient attention to critical transitions in the Systems Engineering lifecycle can lead to "national embarrassment" even in basically successful projects – a notable example being the teething problems when Heathrow Terminal 5 opened in March 2008, which forced the resignation of three senior executives. The inherent quality and flexibility of the design allowed rapid recovery.

Perspective

1. *Systems Engineering needs to be done both "up front" and "through life".*
2. *There is an increasing need for agile approaches to Systems Engineering to suit more dynamic market and operating conditions.*
3. *Systems Engineering needs to be applied with reference to the right system context and boundary otherwise the effort is applied to solving the wrong problem.*
4. *Systems Engineering can only deliver its full potential benefit when integrated with the business decision-making process.*
5. *We in the UK need to improve the way we approach "systems" and complexity. Systems Engineering is part of the solution, taking a holistic perspective which is a key enabler for this improvement.*

Systems Engineering in Government

An indication of Government interest in Systems Engineering is the increasing membership of Government agencies in the INCOSE UK Advisory Board. As of June 2008, these are MOD's DE&S, DSTL, HMGCC, and GCHQ.

The number of roles requiring Systems Engineering as a primary or important skill in these organisations is in excess of 1,000. All four organisations have active process and skills development programmes with the objective of filling identified skills gaps. DSTL intends to raise the systems competency of about 500 of its employees by at least one stage over the coming 3-5 years.

Other Government agencies that make extensive use of recognisable Systems Engineering and enterprise engineering approaches, process and suppliers include DCLG, NHS and the Identity and Passports Service.

Perspective

The increasing Government awareness of and commitment to Systems Engineering is welcomed. However industrial experience shows that it will take several years of sustained effort, investment and consistent and committed leadership for the change to become institutionalised and consistently applied, and for the benefits to be realised; continuing investment will then be required to sustain the improvement.

Systems Engineering in industry

A preliminary indication of Industry interest in Systems Engineering is given by the industrial spread of INCOSE UK membership. Many of the major defence and aerospace contractors are represented, and also a wide spread of other industries notably transport and infrastructure and complex product development. An analysis and full listing of employers of INCOSE UK membership is given at Annex 2.

The industry members of the INCOSE UK Advisory Board were, as of June 2008:

Company	Sector
BAE SYSTEMS	Defence & Aerospace
Thales UK	Defence, Aerospace & Security
QinetiQ	Defence & Security
Selex Sensors and Airborne Systems	Defence & Aerospace
EADS Astrium	Defence & Aerospace
General Dynamics UK	Defence & Aerospace
Ultra Electronics	Defence & Aerospace
Atkins	Infrastructure, transportation, consultancy
Halcrow	Infrastructure, transportation
Detica	Information systems
Harmonic Ltd	Consultancy, SME
Vega Group Plc	Consultancy
Telelogic	Tool vendor and training
The Salamander Organisation Ltd	Tool vendor and consultancy, SME
AWE	Defence
Rolls Royce	Defence & Aerospace, other

Many of these organisations run in-house training for their systems engineers and for those who have to apply Systems Engineering methods in their work. A wide range of training is available for practitioners in systems skills and techniques from commercial providers. This kind of training is often good, but lacks consistent accreditation and quality standards, and is often provided by tool vendors in which case the methods taught may be tied to a particular tool. To use Systems Engineering tools without a complementary capability in systems thinking is unlikely to lead to good system solutions.

An estimate of the industrial significance of Systems Engineering

The MOD conducted a survey of a limited sample of defence companies as part of the development of Version 2.0 of its Defence Industrial Strategy in the latter part of 2007. While the data is not complete or fully consistent, it does allow us to make an initial estimate of the industrial importance of Systems Engineering in the UK economy.

The spectrum of answers ranged from ~30% to ~60% of staff "involved in Systems Engineering" and from ~5% to ~10% as "primary job function". The total number of UK employees employed by organisations represented by the sample was of the order of 50,000. The "primary job function" figures scale up to a very large number across the defence and aerospace industry: over 10,000, based on the figures quoted in the sample and the percentage of the industry represented by the sample. Assuming a nominal "added value per employee" for the sector of £100k, this equates to an annual spend of the order of £1bn on Systems Engineering, enabling £10 Bn-worth of business and avoiding of the order of £2Bn unforeseen cost due to better risk handling. This is broadly consistent with a top-down figure derived from the UK defence acquisition budget and volume of exports plus other major Public Sector procurements. It would be more difficult to arrive at a valid figure for non-defence Systems Engineering; but there is significant Systems Engineering activity in the motor industry, civil aviation, infrastructure and transport sectors. It is probably not unreasonable to estimate the following figures for the importance of Systems Engineering to the UK economy:

	Lower bound	Most likely	Upper bound
Direct Systems Engineering spend	£0.5 Bn	£1-1.5 Bn	£5 Bn
Business value enabled by UK Systems Engineering capability	£5 Bn	£10-15 Bn	>£50 Bn

Perspective:

Not withstanding the growth in specialist Systems Engineering degree provision, the academic sector's output could not currently support the likely turnover (~10%) in the professional population, let alone the anecdotal estimates of expected growth. This means that there must be some other sort of supply and demand model operating to meet (or not) the demand for professional systems skills in Industry.

Another interesting observation is that, even after rapid growth, the INCOSE membership comprises less than 10% of those doing Systems Engineering as their primary job – and by no means all INCOSE members have Systems Engineering as their primary job function; as few as 40% by some estimates. On the other hand the UKAB (2008 membership) probably represents a very significant part, if not the majority, of UK Industry employing Systems Engineers as measured by the percentage of the total number of Systems Engineers employed in the UK.

Systems Engineering Career Paths

Few practising systems engineers have formal qualifications in Systems Engineering, and many are not engineering graduates. Their backgrounds include physics, [18] mathematics, operational research, a wide range of other sciences notably the cognitive sciences, biological sciences and system operation. Many achieved chartered status through their original scientific or engineering discipline, and acquired systems competencies in mid-career.

In recent years, people with first and post-graduate degrees in Systems Engineering have entered the workforce. Opinions are divided as to how effective such "direct entries" will be in Systems Engineering jobs. There is a wide range of opportunity for them; the challenge both for educators and employers will be to encourage them into areas where they can apply their skills quickly and effectively, and gain the practical delivery and domain experience required for them to become competent practitioners.

In summary:

- > few practising systems engineers have a formal qualification in the subject
- > there are two traditional routes into Systems Engineering – engineers who grow into systems roles, and non-engineers who come in "from the side"
- > a third route is now appearing in the form of direct graduates with Systems Engineering degrees; these people will need a different type of induction into work because of their different initial skillset.

Perspective

In the UK, practising systems engineers have a wide range of backgrounds, seldom including formal Systems Engineering education. Most of these people are highly skilled and experienced and make good decisions within their range of experience and competence. However their background will most likely be "unbalanced", reflecting the way their experience has evolved through a particular career and professional development path.

In a recent cross-institution workshop on system professionalisation, a key insight to emerge was that organisations take a very large and poorly understood risk when they entrust key systems decisions to people who do not have the background to understand the systems issues. If senior decision makers' background is "lopsided", not only do they not have the experience to make the decision, they may not "know what they don't know" and therefore not understand the risk to which they are exposing the organisation. [19]

[18] Anecdotally, up to 50% in small-scale informal surveys held at meetings of senior practitioners
[19] INCOSE Systems Engineering Professionalisation Workshop, held at the RAEng on 16 May 2008, involving RAEng, IET, InstMC, EC UK, INCOSE Certification Team and INCOSE UK.

Systems Engineering Competencies and Accreditation

INCOSE's UK Advisory Board (UKAB) has been running a project for several years to develop and validate a "Systems Engineering Core Competency Framework".

The Systems Engineering Core Competency Framework Version 2 and the companion Guide to Competency Evaluation can be downloaded from:
www.incoseonline.org.uk

The framework is in use in a number of the UKAB member organisations, including UK MOD. Some organisations use it unmodified while others have tailored it or adapted it to fit with their organisational practices and methods.

INCOSE International has developed a "Systems Engineering Professional" certification programme. Currently three designations are available:

> ASEP – Associated Systems Engineering Professional, which is achieved by taking an invigilated on-line examination based on the INCOSE Systems Engineering Handbook; this is based in turn on the international standard ISO/IEC 15288, so is of international relevance.

> CSEP – Certified Systems Engineering Professional, which in addition to the on-line examination requires a Bachelor level technical degree and five years Systems Engineering experience, endorsed by three competent systems engineers who know the candidate. Again this qualification is potentially of international relevance, though so far take up outside the US is limited.

> CSEP-Acq - Derivatives of CSEP are being developed. The first, CSEP-Acq, is for acquisition specialists. Since this is based closely on courses run by the US DoD Defence Acquisition University, its applicability outside the US is very limited.

INCOSE UK and IET have assessed CSEP against the UK-SPEC criteria for chartership and concluded that the UK-SPEC requirements are more demanding in certain respects. CSEP aligns most closely to the IEng level of UK-SPEC. It therefore usefully complements but is not a substitute for Chartered designation from a UK professional body.

A further designation, ESEP – Expert Systems Engineering Professional – is being developed, and efforts are underway to align it to UK requirements at a level corresponding approximately to the Fellowship level of UK professional institutions.

Perspective

Benchmarks suitable for use as professional standards for Systems Engineering now exist but are not yet widely applied.

Systems Engineering CPD (Continuous Professional Development)

We have already remarked that few systems engineers have professional qualifications in the subject. There is a widespread and contentious belief that "you can't teach Systems Engineering to people who haven't yet made 5 years' worth of mistakes".

Many employers provide CPD using in-house resources, universities or commercial training providers, and ranging from half-day awareness courses to 2-year systems architect development programmes. Some of these in-house programmes are managed through rigorous adherence to competency frameworks, often derived more or less directly from the INCOSE UKAB framework.

Many systems engineers use INCOSE and other Systems Engineering conferences and publications to develop their competencies through self-study. Some universities (including Cranfield, Bristol, Loughborough) provide modular short courses that can be optionally joined up to form a PG Cert or MSc.

Systems Engineering Education

Three universities are members of the INCOSE UK Advisory Board:

> UCL
> Loughborough University
> University of Bristol.

Around 40 universities do some Systems Engineering or related activity. Annex 5 lists all of these, and seeks to give some indication of the nature and level of the activity and the "style" of approach.

The following paragraphs consider Systems Engineering in education and research, starting at the beginning – in schools – and moving through the stages of education.

Systems Engineering in schools

The new "Design and Technology" GCSE course is an excellent introduction to basic concepts of integrated design, and prepares students for the more advanced concepts of Systems Engineering as a development process.

Physics and Mathematics – the "feedstock for engineering" – are critical skills for systems engineers who will be responsible for the "hard" aspects of problem analysis and solution development. The health of these subjects in schools today will determine the health of the UK's systems capability in 20 years' time.

Pilot studies have taught systems concepts to schoolchildren, some as young as 9.

Systems Engineering at undergraduate level (BEng and MEng)

A search of the UCAS website shows:

> From a 1st level search on 'systems' – 100+ subject areas
> From a 2nd level search on 'Systems Engineering' – as Annex 3.

Some undergraduate courses are advertised as "Systems Engineering in xxx" and aim to produce "Level 1" systems engineers (p5 above), with an ability to produce complex systems within a homogeneous technology or domain. Examples of these are listed in Annex 3, such as the Coventry "Systems Engineering" course, which focuses on "Software Systems Engineering", so would be regarded as "Level 1".

There is a small but increasing number of university courses in Systems Engineering (levels 2 and 3) per se. There is not as yet a consensus on what should be covered in a Systems Engineering undergraduate course, and there is debate on whether systems engineers will be effective in employment without an academic grounding and delivery experience in a more specialist engineering or science discipline. Two courses appear to contain content that would fall into a definition of Systems Engineering consistent with INCOSE products, ISO15288, and General Systems Theory. This assessment is subjective and the brief content description may not reflect the true course content:

> Loughborough – Systems Engineering
> University of Sheffield – Systems and Control Engineering

A small number of "Engineering with Engineering (or Enterprise) Management" courses appear to introduce concepts and skills relevant to Systems Engineering management. The following courses, from the description, have a significant Systems Engineering content:

> University of Strathclyde, MEng in Engineering and Enterprise Management
> University of Bristol, MEng in Engineering Design with Study in Industry

The latter course is heavily mathematical, has strong industry sponsorship, and targets high fliers expecting to manage the development of "complex systems that will have a major impact on society".

There may be other relevant courses hidden under other esoteric headings. A 1st level search on 'Design' reveals 200+ subjects – some examples are given in Annex 3 – while a 2nd level search on 'Architectural Design' shows nothing.

A Systems approach in undergraduate teaching of Engineering

The Engineering Council requirements for accreditation of Higher Education programmes are available at:
http://www.engc.org.uk/documents/Accreditation_HE_Programmes_RP.pdf
They include the specific learning outcomes required of accredited Engineering programmes by EC^{UK}. On page 10 there is a specific requirement that graduates should have an "understanding of and ability to apply a systems approach to engineering problems".

The Royal Academy of Engineering has established Visiting Professorship schemes, which seek to provide systems input to undergraduate engineering courses. Currently there are 24 RAEng Visiting Professorships in "Integrated System Design" and 16 in "Sustainable Systems" at 26 universities. These universities are listed in Annex 4.

These and other universities have also recruited a number of Visiting Professors in Systems Engineering through other mechanisms.

Perspective

Universities are now responding to the need for a systems approach in their engineering teaching, and for Systems Engineering as a skill in its own right, leading to a large number of undergraduate courses covering the subject at some level. The authors of this report unreservedly welcome this trend. There is however an evident and growing need for some degree of coherence to help industry select the right courses to recruit from, to help academia provide courses relevant to industry needs, and to facilitate professional recognition of graduates.

INCOSE UK has affiliated to the Engineering Council and is actively pursuing the definition of a core curriculum for Systems Engineering, with a view to establishing or enabling a capability for course accreditation and professional recognition.

A wider search would have to examine complexity science, system dynamics, operational research and cognitive science as four of a number of closely allied disciplines. This is work for a future issue.

Systems Engineering at MSc level

The following Masters level programmes are specifically focussed on Systems Engineering:

> Loughborough, MSc in Advanced Systems Engineering
> UCL, MSc in Systems Engineering Management
> Cranfield/Defence Academy, MSc in Systems Engineering for Defence Capability
> University of Bristol, MRes in Systems (starting October 2008)

Other courses with significant Systems Engineering content:

> UCL, MSc in Environmental Systems Engineering
> University of Bath, MSc in Engineering Design
> University of Bristol - UWE collaboration CPD Aerospace MSc

Also of interest:

> Open University: a Systems Engineering module is compulsory in various courses (1/6 of the content) e.g. the MSc in Technology Management. [20]

Systems Engineering at PhD/Eng Doc level

Twenty-five Engineering Doctorate centres are now in existence; 5 each from the first 3 calls in 1992, 1997, and 2001; 3 from the 2003 call; 6 since 2004 through the Collaborative Training Award; and the new Large Scale Complex IT Systems (LSCIT) one starting in 2009. Since 1992, over 1250 Research Engineers (RE) have enrolled, sponsored by over 510 different companies. [21]

Of the 25 centres, 11 have a significant emphasis on a systems approach and/or Systems Engineering. Two, at Loughborough [22] and Bristol, [23] are specifically focused on "Systems Engineering".

In March 2007 EPSRC published a 'Report of a Review of the EPSRC Engineering Doctorate Centres, March 2007'. [24] This puts the Eng Doc schemes in perspective and notes that they account for about 30% of the EPSRC spend on user focused postgraduate training schemes. One of the 6 main recommendations made in the report was that: "EPSRC should work with Engineering Council UK to engage the relevant Professional Institutions to ensure that the Engineering Doctorate Programmes are professionally accredited and that there is a clearly visible career path for Research Engineers through to Chartered Engineer status."

Funding for the Engineering Doctorate Centres was re-competed in late 2008, changing the landscape considerably. Forty four "new" Doctoral Training Centres have been funded, including about 16 Engineering and Industrial Training Centres. [25] Some of these are completely new; some are continuations of established ones. Of those relevant to Systems Engineering, some secured ongoing funding, while others will take in their final tranche of EPSRC funded students this year.

Perspective

The autumn's EPSRC funding decisions substantially changed the landscape of UK Industrial Doctorate programmes in systems topics. The loss of some useful programmes is cause for concern and emphasises the need for the systems community to make its case with consistency and intellectual rigour, and with full regard to the economic benefit.

[20] http://www3.open.ac.uk/courses/bin/p12.dll?C01T837
[21] http://www.epsrc.ac.uk/PostgraduateTraining/Centres/EngD/Centres.htm
[22] http://www.lboro.ac.uk/departments/el/sedc/engd.html/
[23] http://www.bristol.ac.uk/engineering/systemsengd/
[24] http://www.epsrc.ac.uk/CMSWeb/Downloads/Other/EngDReviewReport.pdf
[25] http://www.epsrc.ac.uk/PostgraduateTraining/centres/newcentres.htm

Systems Engineering Research

Here we identify UK research activities with explicit Systems Engineering objectives. Many other research initiatives involve systems skills and techniques to a greater or lesser extent.

> The NECTISE (Network Enabled Capability Through Innovative Systems Engineering) research programme is jointly funded by BAE SYSTEMS and EPSRC and involves several universities.
> The Systems Engineering for Autonomous Systems Defence Technology Centre also has a Systems Engineering research strand.

The Systems Engineering Innovation Centre at Loughborough is a joint venture between BAE SYSTEMS, Loughborough University and the East Midlands Development Agency. Frazer-Nash and DSTL have become partners, and SEIC is seeking wider participation with aspirations to become a national centre. Loughborough University will host the Conference on Systems Engineering Research in 2009, the first time this conference has come to the UK.

MOD has established the Software Systems Engineering Institute, which will seek to conduct a mixture of research and spreading best practice in the engineering of complex "software systems". This is an industry collaboration managed by MOD's new Systems Engineering and Integration Group.

The University of Bristol has a Research Group that has focused on Infrastructure and includes the 'Safety Systems Centre' and the 'British Energy Systems Performance Centre'.

On the related subject of complexity, there are two EPSRC funded Complexity Centres, at University of Bristol and University of Warwick; and the LSCIT (Large Scale Complex IT Systems) research programme run jointly by York, St Andrews, Oxford and Bristol has funding for an Eng Doc programme, which will start in 2009.

There is a lot more Systems Engineering research going in the Defence R&D programme than is listed. The challenge is finding it because it is usually wrapped up under another heading. For example, research into how to engineer Open Systems has been variously badged as research into "enabling technology insertion" and "reducing whole life costs". More appears under the banner of Operational Research or Management Science. [26]

The EPSRC programme has recently been restructured to encourage synergies across disciplines with two thrusts: "business innovation" and "research base". The latter, "to establish a healthy platform for a future science and engineering base and secure the future supply of people", includes a programme for "cross-disciplinary interfaces". [27]

There is significant on-going research funded by EPSRC and the DTI. 'Rail Research UK [28] : the EPSRC funded universities' centre for railway systems research' was launched in February 2003 and aims to work alongside industry with the aim of creating a world-class rail system for the UK. The £7 million centre involves 12 research groups from 7 universities and is jointly led by the Universities of Birmingham and Southampton. The research has three themes: Engineering Interfaces; Whole System Performance; and Users, Community & Environment.

In April 2005 the Department f Trade and Industry (DTI) ran an industrial collaborative research call for "the validation of complex systems", to address technological advances where any single product or service, or combinations of products and services, involve a vast array of components and systems that interact in unpredictable ways. Validation of such complex systems prior to product development requires the development of, often large-scale, platforms for integrated demonstrations. There are currently five major industrial research projects running as a result of this call that continue to be supported by the Technology Strategy Board. [29] (originally under the DTI). These projects are:

> **HipNet Heterogeneous IP Networks** - HIPNet is a 3.5 year project, led by Ericsson, with two other industrial partners and four universities, with the objective 'to develop expertise for the design and implementation of advanced next generation IP telecommunications networks (NGNs), under traffic growth conditions, including the impact of new services and technologies'.
> Total Project Cost is: **£21,120,996.00** of which the technology programme is providing: **£5,847,608.00**
> The project started on 1 January 2006 and runs for 42 months.

> **Integrated Wing** - The Integrated Wing Aerospace Technology Validation Programme is a core element of the National Aerospace Technology Strategy and will provide the means to integrate and validate advanced wing aerodynamics/loads, structures and systems. 'Phase 1' is a 3 year £34M programme addressing integrated technologies for exploitation in the 5 to 7 year timeframe.

> **Environmentally Friendly Engine** - The EFE project is aimed at enhancing UK competitiveness in the fields of high temperature materials, high efficiency turbines, low emissions combustion, manufacturing technologies, engine controls, and nacelle aerodynamics. It is a collaborative venture led by Rolls-Royce with four key UK partners, Bombardier, Goodrich, Smiths and HS Marston.

[26] Comment from one contributor: "One of my hobbyhorses is that to be world class you have to be operating at the cutting edge: whether you call this "leading the thinking", or "leading the development of practice", or research doesn't much matter but it's an important indicator of health One of the benefits of setting out to create a national research agenda for SE is that it would act as a catalyst to search out and discover these links."
[27] EPSRC Connect, Apr 2008, Issue 60; (EPSRC = Engineering and Physical Sciences Research Council)
[28] http://portal.railresearch.org.uk/RRUK/default.aspx
[29] http://www.innovateuk.org/home.ashx

Total Project Cost is: **£94,946,489.00** of which the technology programme is providing: **£30,000,000.00**
The project started on 1 January 2006 and runs for 48 months.

> **Validation of Future Non-Road Machines** - The Europe/US off-road machine market has sales of 700,000 machines worth £37Bn/year with growth currently at 4-30%/year, depending on market segment. New emission legislation, and customer demands for more functionality and productivity, will drive an unprecedented increase in vehicle systems complexity. Building and validating the thousands of variants using traditional approaches is economically unattractive; new approaches are required.
Total Project Cost is: **£5,520,480.00** of which the technology programme is providing: **£1,998,240.00**
The project started on 1 January 2006 and runs for 60 months.

> **ELGEAR** - There is an aim to remove aircraft engine driven hydraulic pumps in order to improve efficiency and reduce emissions. This research project will use and validate a model based design approach that will be used to optimise aircraft system architecture and provide data for safety case developments.
Total Project Cost is: **£11,172,766.00** of which the technology programme is providing: **£4,469,106.00**
The project started on 1 February 2006 and runs for 43 months.

Systems Engineering in Professions

Royal Academy of Engineering: The Royal Academy of Engineering is committed to furthering the development of systems skills across the whole engineering community.

Engineering Council UK: The Engineering Council is aware of the need for better coverage of Systems Engineering as a skill that is relevant, though not necessarily core, to many of its members and affiliates. INCOSE UK is now a Professional Affiliate to the Engineering Council.

Science Council: Many systems engineers were educated as Physicists and some aspects of complexity science are key to the successful design and operation of very large-scale complex systems. The Science Council's web site gave no hits for "Systems Engineering" and only two for "systems".

Chartered Institutions: The IET has a large Systems Engineering Professional Network and has an MoU with INCOSE with the aim of furthering professional recognition and accreditation. Other institutions are anxious to be able to accredit claimed Systems Engineering experience as part of their chartership programmes: including the Institute of Measurement and Control, which has signed an MoU with INCOSE UK to further this objective.

Engineering Council Affiliates: Some established "architecting" institutions (for example buildings, Naval Architects) operate in a way that might be a future model for Systems Engineering.

Other Bodies: with interests relating to Systems Engineering include the System Dynamics Society, the Design Society, the Operational Research Society, APM (Association of Project Management, also an ECUK affiliate), and the international College of Complex Project Managers.

International Comparisons

There is a significant scope and branding issue for Systems Engineering worldwide. In this report we have tried to be inclusive and to indicate the breadth of scope and stakeholder interests covered by the term. Interpretation of Systems Engineering ranges from "a holistic approach to the creation of successful systems" to "a systematic process for technical project management". This makes international comparisons difficult – it even makes it difficult to compare Systems Engineering consistently across different parts of the same company. Below we discuss a few indicators that we believe are meaningful.

The UK has its own distinctive heritage of Systems Engineering. The air defence system that controlled the Battle of Britain was the first integrated "networked system", and remains an exemplar of the type. The discipline of Operational Research was developed during WW2 to apply systems thinking and quantitative methods at a national and strategic level to optimise many aspects of the war effort. "Soft Systems Methodology" was developed in the UK, pioneered by Checkland during the 1970s, to find better ways to design systems to serve human and organisational purposes. Derek Hitchins, the first President of the UK Chapter of INCOSE and now an INCOSE Fellow, has been hugely influential in shaping the thinking of the current generation of UK systems practitioners and is recognised internationally.

The UK Systems Engineering community is again "punching above its weight" internationally according to indicators such as INCOSE membership – the UK Chapter has over 10% of the worldwide membership, and has consistently been one of the most active and top performing Chapters worldwide. We believe this reflects the existence of a vibrant professional systems community in the UK – which is increasingly influential in Government as witnessed by the Systems Engineering focus in the Defence Innovation Strategy, the RAEng commitment to "systems", and the emphasis on a holistic cross-discipline approach in the new EPSRC programme structure.

There is a healthy UK representation in the papers presented at conferences such as the INCOSE International Symposium and the Conference for Systems Engineering Research, but not in proportion to the INCOSE membership. This may reflect the more mature development of Systems Engineering in academia in some other countries notably the US, Israel, and Northern Europe.

There is very rapid growth of interest in Systems Engineering in the Far East. Japan has adopted NASA Systems Engineering approaches for its space programme; China, Korea and Singapore are actively engaging in the international systems community; Singapore will host INCOSE's 2009 International Symposium, its first time in Asia.

Industrially, the UK is very successful worldwide in securing major infrastructure contracts. There is however a persistent belief that we "can't do major projects" at home – a perception exacerbated by the negative press coverage on issues such as the Millenium Dome, the teething problems with Heathrow Terminal 5, and any problems in major Government IT and defence programmes.

The US DoD has a well structured programme and explicit certification requirements [30] for the Systems Engineering skills it considers necessary for defence acquisition skills, delivered by the Defence Acquisition University.

There is a very open market for systems integration in UK Government acquisition. This should be a good thing in terms of allowing the UK to access the best systems integration capabilities worldwide. However it places a very heavy demand on the Systems Engineering capabilities of Government to intelligently choose between and manage such a diverse range of suppliers.

Perspective

There is no overwhelming evidence that the UK is doing worse than other countries in its application of Systems Engineering; but there is room for improvement in the way we in the UK develop our systems knowledge, capability and capacity and convert them into business outcomes. There is a need for more systems awareness across the whole engineering, project management and commercial community, and for a more consistent professional identity for systems engineers and systems-trained professionals.

There is evidence (e.g. from the balance of INCOSE membership worldwide) that the range of sectors and organisations actively seeking a Systems Engineering capability is increasing (e.g. transportation). This increasing demand will further exacerbate the shortage of skilled systems engineers.

Summary and Conclusions

We conclude that systems skills are important to the UK economy. Here we recapitulate the key "headline numbers" and critical recommendations identified throughout the report.

> Ten years ago three universities were considered to be active in Systems Engineering; now several are considered to be of high quality and around 40 offer courses in Systems Engineering or closely related subjects. Annex 5 lists all of these, and seeks to give some indication of the nature and level of the activity and the "style" of approach.

> At least 2/3 of the employers represented in INCOSE's UK Advisory Board` are actively recruiting Systems Engineers, and investing in in-house competency assessment and skills development programmes.

> The Royal Academy of Engineering has published a report identifying a serious risk of critical shortfalls in the UK's systems integration capability and is funding visiting professorships at over 40 universities in Systems-level and cross-disciplinary engineering. [31]

> A recent survey conducted by MOD indicates that there are of the order of 10,000 Systems Engineering jobs in about 20 major defence contractors in the UK. These jobs leverage about 10-20 times as many in those companies. It is reasonable to assume that these trends are replicated in the non-defence sectors that apply Systems Engineering.

> The spectrum of answers reported between ~30% to ~60% of staff "involved in Systems Engineering" and from ~5% to ~10% had Systems Engineering as their "primary job function". Extrapolating the data, it is probably not unreasonable to estimate the following figures for the importance of Systems Engineering to the UK economy:

	Lower bound	Most likely	Upper bound
Direct Systems Engineering spend	£0.5 Bn	£1-1.5 Bn	£5 Bn
Business value enabled by UK Systems Engineering capability	£5 Bn	£10-15 Bn	>£50 Bn

> There is a need to improve the standing, recognition and reputation of Systems Engineering in the academic and professional community, and to establish an agreed academically sound foundation for the subject.

> Many competent and effective systems engineers come from outside engineering. Their skills must be exploited and their needs recognised as we set the professionalisation and education agendas.

INCOSE UK Chapter is committed to an inclusive approach working with a wide range of stakeholders to improve the condition of Systems Engineering in the UK and its contribution to the UK economy and the wellbeing of UK-based engineering and technology organisations.

[30] http://www.dau.mil/workforce/index_sub5_CareerFildCertStandardsFY08.asp
[31] See Annex 4

Appendices

Annex 1: Systems Engineering Standards, maturity models and guidance

Aspects of Systems Engineering have been codified in various standards, maturity models and guidance, the most important of which are:

Standards

- ISO/IEC 15288 – "System Life Cycle Processes": provides a through life overview of systems lifecycle and organisational processes to support system development and operation;
- EIA 632 - "processes for engineering a system": provides a good basis for defining and engineering complex cross-discipline systems, widely used in the defence and aerospace sectors;
- IEEE 1220-1998 - "Standard for Application and Management of the Systems Engineering Process": at the "hard end" of "hard" Systems Engineering, with less emphasis on understanding stakeholder needs and more on the practicalities of developing complex "system products".
- Sys-ML – Systems Modelling Language, is an extension of UML (the Unified Modelling Language) incorporating concepts required to support the analysis of Systems Engineering problems and definition of system solutions.

Maturity models

- CMMI Version 1.1 PM/SE/SW/SM – integrated capability maturity model for Systems Engineeering, project/programme management, software engineering and supplier management
- CMMI Acquisition Module
- ISO/IEC TR 15504 Part 6- "Process assessment -- Part 6: An exemplar system life cycle process assessment model": uses ISO/IEC 15288 as the process reference model for assessing the maturity of an organisation's capability to perform Systems Engineering according to the ISO process maturity assessment.
- ISO/IEC 14291 – capability maturity model for assessing against ISO 15288
- Systems Engineering Competency Framework – INCOSE UK Advisory Board 2005 and 2007

Handbooks and guidance for practitioners

- INCOSE Systems Engineering Handbook – free download to members
- INCOSE UK Chapter 1-page guides on Systems Engineering: www.incoseonline.org.uk
- NASA Systems Engineering handbook – a very good and comprehensive guide to the creation of one-of-a-kind mission critical systems
- UK MOD draft Systems Engineering handbook and Engineering Principles: http://www.ams.mod.uk/aofcontent/operational/business/engineering/engineering_principles.htm

"Awareness level" handbooks and guidance

- Defence Industrial Strategy Chapter B1
- RAEng report on Integrated System Design: http://www.raeng.org.uk/education/vps/pdf/RAE_Systems_Report.pdf

Annex 2: Employers of INCOSE UK membership

Summary data

The INCOSE UK membership when sampled during the early summer of 2008 was 719. Of these, 112 gave no organisational allegiance. Of the remaining 607, 302 (almost exactly 50%) were employed by divisions of the 15 companies and Government organisations listed below. The remaining 50% were employed by just short of 200 organisations listed in the table on the next page.

About 86% of INCOSE UK's members work in commercial organisations, ranging from major multi-national systems companies to sole traders. 8% work in Government and 6% in universities.

Organisations employing at least 1 member	211	
Of which the top 15 by individual membership are:		
BAE Systems	32	
QinetiQ	31	
Thales	31	
WS Atkins	30	
Lockheed Martin	26	
UK MOD	25	
Finmeccanica (Selex, Agusta-Westland, VEGA)	20	
BT	17	
Rolls Royce	16	
AWE	14	
GD UK	13	
DSTL	12	
MBDA	12	
Ultra	12	
Babcock	11	
Top 15 :	302	
50% of INCOSE UK membership is employed by the "top 15" organisations		
Total members on date of sample	719	
Number who gave no allegiance	112	
Number who gave an allegiance	607	
Of which:		
Government	47	8%
Universities	36	6%
Rest	524	86%

All employers of INCOSE UK membership excluding "top 15"

3SL Inc
Achievement Advance! Ltd
Aerospace / Defence
Aerosystems International Ltd
Agere Systems
Airbus UK
Alcatel-Lucent
Aldersgate Partners LLP
Aldpartners
Amalga Limited
Apogee Consulting
Arbutus Tech Consulting Ltd
Artisan Software Tools Ltd
A-STEM

Bailey Rail
BIW Technologies
BMT Defence Services
BMT Sigma Limited
Boeing Defence Ltd
Bombadier Transportation LUPD
Bombadier Transportation UK Ltd
Booz Allen Hamilton Ltd
Brass Bullet Ltd
Briarton Ltd
Bristec Ltd
Burge Hughes Walsh Partnership

C4 Systems Ltd
Callisto Consulting Ltd
Cardiff University
CEMMNT Hub Ltd
Chilean Army
CiGi Technology Ltd
City University
Claverham Ltd
Clayton Consultancy Ltd
Cohesive Services Limited
Comply Serve Limited
Consultant Q
Control & Dynamics Ltd
Corata Ltd
Cornwell Management Consultants
Corus
Cranfield University
Critical Software, SA
CSC
cshepherd.co.uk
david.martin
Design & Testability Ltd
Detica Ltd
Devonport Royal Dockyard Limited
DML
Domino UK Ltd

EADS
EADS Astrium Ltd
Elipsis Ltd
Emente Ltd
ENJ Consulting
ETS Ingenieros Industriales / Universidad Politecnica de Madrid
Eurostep

Harmonic Limited
Headmark Analysis Ltd
HMG
HMGCC
Hood Group
HOSOB
Hospital Universitario Germans Trias i Pujol. Badalona

IBM UK
IBM UK Limited
IBM UK Ltd
Imperial College London
IMR 4U Ltd
Independent Consultant
INPE LIT, ITA
Institution of Mechanical Engineers
INSYSCO Ltd
Insyte
Integrate se
Interfleet Technology
IPL
IS&S Ltd
Itsfitz Ltd
ITT

Jacobs UK Ltd
JM Associates
John Boardman Associates Ltd

Ken Jackson Associates
KPIT Cummins Infosystems Ltd
KS Consultancy

Land Transport Authority
LEP Systems Ltd
Lloyd's Register MHA Limited
Logica CMG
London Overground Infrastructure - Transport for London
London Underground
Loughborough University
Loxcius Ltd

Manna Solutions Ltd
MARTREK Ltd
Meggitt Avionics
MetaWave Video Systems Ltd
Metronet
Middlesex University
MirvSys Ltd
Motorola Ltd
Mott MacDonald
Mouchel
Mullard Space Science Laboratory, UCL

NATS
NBPT (Mids) Ltd
Network Rail
Network Rail (UK)
Nicholas Coutts Ltd
Nokia Networks
Nokia Siemens Networks
None

Observe
Ocean Contracts Ltd
Open University

Rail Safety and Standards Board
Raytheon Company
Risk Covered
Robert Briggs & Associates Ltd
Rockwell Collins (UK) Ltd
Roke Manor Research Ltd

S.E. Validation Ltd
Scott Wilson
SEIC, Holywell Park
Serco Ltd
Signalling Solutions Ltd
Smiths Aerospace
SPIDRE LTD
STFC-Rutherford Appleton La.
Stratum Management Ltd
Sula Systems Limited
Supersonic Systems Ltd
Surrey Satelitte Technology Ltd
Surrey Tech. Centre
SyntheSys
System Level Integration Ltd
Systems Engineering & Assessment Ltd
Systems Engineering Innovation Centre (SEIC)

TDSi
TELECOM MODUS LTD
Teledyne TSS Limited
Telelogic UK
The Cube Farm
The Defence Academy
The Mathworks Ltd
The MITRE Corporation
The Real Time Data Co Ltd
The Right Requirement Ltd
The Salamander Organisation
Trinity House
TRW Automotive
Tube Lines Ltd

UAV Tactical Systems
UBS
UCL
UK AC
University College London
University of Birmingham
University of Bristol
University of Cambridge
University of Leeds
University of Sussex
University of Westminster
University of York

Vectra Group Ltd
VEGA Group PLC
Visteon UK Ltd
Visual Exemplars Ltd

Weir Strachan & Henshaw
Westinghouse Rail Systems Ltd

Xerox Corporation
Xerox Ltd

X-Net Ltd

Annex 3: Systems Engineering and related courses in UK Universities

3.1: "Systems Engineering" hits from UCAS website for 2008 – (excludes Cranfield)

The University of Birmingham (B32)	**Qualification**
Computer Systems Engineering (3/4 years) (H602) [EP]	3FT/4FT Hon BEng/Meng

University of the West of England, Bristol (B80)	**Qualification**
Aerospace Systems Engineering (H430) [EP]	3FT/4SW Hon BEng
Aerospace Systems Engineering (H431) [EP]	4FT/5SW Hon MEng

Castle College Nottingham (C21)	**Qualification**
Computing (ICT Systems Support) (306H) [EP]	1FT HNC

Coventry University (C85)	**Qualification**
Systems Engineering (H650) [EP]	3FT/4SW Hon BEng

University of Greenwich (G70)	**Qualification**
Systems Engineering (H650)	3FT/4SW Hon BEng

Lancaster University (L14)	**Qualification**
Mechatronics (HHH6)	4FT Hon MEng

University of Leicester (L34)	**Qualification**
Embedded Systems Eng/USA with Industry (4 years) (GHQ6)[EP]	4FT Hon BEng
Embedded Systems Eng/USA with Industry (5 years) (GHP6) [EP]	5FT Hon MEng
Embedded Systems Engineering (HG66) [EP]	3FT Hon BEng
Embedded Systems Engineering (4 years) (HG6P) [EP]	4FT Hon MEng
Embedded Systems Engineering (USA) (GH66) [EP]	3FT Hon BEng
Embedded Systems Engineering (USA) (4 years) (GH6P) [EP]	4FT Hon MEng

Loughborough University (L79)	**Qualification**
Systems Engineering (H652)	3FT Hon BEng
Systems Engineering (4 year MEng) (H660)	4FT Hon MEng
Systems Engineering (4 year SW) (H650)	4SW Hon BEng
Systems Engineering (5 year SW) (H641) [EP]	5SW Hon MEng

The University of Reading (R12)	**Qualification**
Systems Engineering (H650) [EP]	3FT Hon BSc

The University of Sheffield (S18)	**Qualification**
Computer Systems Engineering (4 years) (G500) [EP]	4FT Hon MEng
Electronic, Control and Systems Eng (3 years) (H663) [EP]	3FT Hon BEng
Electronic, Control and Systems Eng w Business (H9N9) [EP]	3FT Hon BEng
Electronic, Control and Systems Eng w Busn Skill (H9NX) [EP]	4FT Hon MEng
Medical Systems Engineering (3 years) (H671) [EP]	3FT Hon Beng
Medical Systems Engineering (4 years) (H670) [EP]	4FT Hon MEng
Medical Systems Engineering with Management (B8N2) [EP]	4FT Hon MEng
Systems Eng with a Foundation Year (4 years) (H653) [EP]	4FT Hon Beng
Systems Eng with a Foundation Year (5 years) (H659) [EP]	5FT Hon MEng
Systems and Control Engineering (3 years) (H690) [EP]	3FT Hon Beng
Systems and Control Engineering (4 years) (H660) [EP]	4FT Hon MEng
Systems and Control Engineering with Bus Skills (H1ND) [EP]	3FT Hon Beng
Systems and Control Engineering with Bus Skills (H9NY) [EP]	4FT Hon MEng
Systems and Control Engineering with Management (H1NF) [EP]	4FT Hon MEng

Staffordshire University (S72)	**Qualification**
Computing Science: Systems Management (G563)	4FT/5SW Hon MEng/Beng

University of Surrey (S85)	**Qualification**
Chemical and Bio-Systems Engineering (3 years) (H8CD)	3FT Hon Beng
Chemical and Bio-Systems Engineering (4 years) (H8C1)	4FT Hon MEng
Chemical and Bio-Systems Engineering (4 years) (H8CA)	4SW Hon Beng
Chemical and Bio-Systems Engineering (5 years) (H8CC)	5SW Hon MEng

The University of Warwick (W20)	Qualification
Automotive Engineering - (Systems Engineering) (H335)	4FT Hon MEng
Computer and Information Engineering - (Systems Engineering) (HH61)	4FT Hon MEng
Electronic Engineering - (Systems Engineering) (H612) [EP]	4FT Hon MEng
Engineering - (Systems Engineering) (H102) [EP]	4FT Hon MEng
Mechanical Engineering - (Systems Engineering) (H302) [EP]	4FT Hon MEng
Systems Engineering (HH36) [EP]	3FT Hon Beng
Systems Engineering (HH63) [EP]	4FT Hon MEng
Systems Engineering - (Automotive Engineering) (HH63) [EP]	4FT Hon MEng
Systems Engineering - (Business Management) (HH63) [EP]	4FT Hon MEng
Systems Engineering - (Computer Engineering) (HH63) [EP]	4FT Hon MEng
Systems Engineering - (Instrumentation) (HH63) [EP]	4FT Hon MEng
Systems Engineering - (Robotics) (HH63) [EP]	4FT Hon MEng
Systems Engineering - (Sustainability) (HH63) [EP]	4FT Hon MEng

3.2: Related courses known or suspected to be systems engineering relevant

University of Bristol (B78)	Qualification
Engineering Design with Study in Industry (H150) [EP]	5FT Hon MEng

In addition: Bristol Offers MRes in systems and CPDA MSc Modules in systems, PhDs in Systems

University of the West of England, Bristol (B80)	Qualification
Creative Product Design (H131)	3FT/4SW Hon BSc
Product Design and Innovation (W240)	3FT/4SW Hon BSc

University of Bath (B16)	Qualification
Innovation & Engineering Design (5 Yr SW) (H762)	5SW Hon MEng

The University of Strathclyde (S78)	Qualification
Engineering & Enterprise Management (HN1F)	5FT Hon MEng
Engineering & Enterprise Mgt (with Dip in Ent) (HN1G)	5FT Hon MEng
Engineering and Enterprise Management (HN12)	4FT Hon BEng

Annex 4: Royal Academy of Engineering Visiting Professorships

Roll of Active Visiting Professors at 18 June 2009

University	SD	ISD
Aberdeen		
Aston		
Bath	1	1
Birmingham	1	1
Bournemouth	1	
Bradford	1	1
Brighton	1	
Bristol		3
Brunel		
Cambridge		1
Cardiff	1	
Central Lancs		
City		1
Coventry		
Cranfield		1
De Montfort		
Dundee		
Durham		
Edinburgh	1	3
Glasgow		1
Heriot-Watt		
Hertfordshire		1
Hull		
Imperial College		1
Kingston		
Leeds	1	
Leicester		
Liverpool	1	1
Loughborough		1
Manchester/UMIST	1	
Newcastle	1	1
Nottingham		1
Open		
Oxford		
Oxford Brookes		
Plymouth		3
Queen Mary		
QUB	1	1
RCA		
Salford		
Sheffield	1	
Sheffield Hallam		
Southampton		
Strathclyde		1
Surrey		1
Sussex		
UCL		1
Ulster		1
Warwick		1
York		1
Total	13	29

Notes: SD = Sustainable Development. ISD = Integrated Systems Design.
44 of the listed universities also have VPs in the “Principles of Engineering Design”.
With acknowledgement to the Royal Academy of Engineering

Annex 5: Universities and other academic institutions with significant interest in Systems Engineering, Engineering Management and Systems Science

This list seeks to be inclusive and makes no assessment of the quality or effectiveness of the institutions' efforts in Systems Engineering. Criteria for inclusion are one or more of:

- Course title includes "Systems Engineering"
- "Engineering with engineering management" or "Engineering Design" style degree
- Effective participation in Systems Engineering research programmes or post-grad teaching
- Visiting professor in Integrated System Design
- Academic staff are active in INCOSE UK and/or present at INCOSE conferences, publish in "Systems Engineering".

Some attempt has been made to indicate the "style" of Systems Engineering covered at the university. Indicators include:

- "Type" of Systems Engineering – Type 1 (within a discipline), Type 2- two or more disciplines – Type 3 – complex sociotechnical systems
- Areas of interest – systems design, engineering management, complexity, software intensive, etc

Summary table of Universities involved in Systems Engineering and related subjects.

University	Bachelors	Meng	MSc/MRes	EngDoc	Research	RAEng VP	Stupples level	Complexity	Eng Mgt	CmplxSwSys	Active staff	CPD Modules
Bath			Y	Y		Y					Y	
Birmingham						Y						
Bradford						Y						
Bristol	Y	Y		Y	Y	Y	2, 3	Y	Y		Y	
Brunel				Y		Y						
Cambridge						Y						
Cardiff												
Coventry	Y						1					
City						Y						
Cranfield				Y	Y	Y	1, 2, 3	Y			Y	Y
Defence Academy (Cranfield)			Y		Y		2, 3				Y	Y
Edinburgh						Y						
Glasgow Caledonian										Y		
Greenwich												
Heriot Watt											Y	
Imperial College						Y						
Inst for Sys Level Int			Y	Y	Y		1				Y	Y
Lancaster												
LSE					Y			Y				
UCL			Y	Y		Y	2, 3				Y	
Leicester				Y								
Loughborough	Y	Y	Y	Y	Y	Y	2, 3				Y	Y
Manchester				Y					Y			
Newcastle						Y					Y	
Nottingham						Y						
Open university									Y			
Oxford				Y							Y	
Plymouth						Y						
Queens Belfast				Y		Y						
Reading	Y											
Sheffield		Y										
St Andrews				Y	Y					Y	Y	
Staffordshire												
Strathclyde		Y		Y	Y				Y		Y	
Southampton				Y								
Surrey				Y		Y						
Ulster						Y						
UWE	Y	Y							Y	Y	Y	Y
Warwick	Y	Y		Y				Y				
York				Y						Y	Y