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UCL education for systems engineers

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Abstract

This paper discusses the emerging discipline of Systems Engineering which is necessary for the effective management of large and complex projects. It describes the post-graduate courses in Systems Engineering provided by the Defence Engineering Group at University College London, and how the knowledge and abilities conferred by these courses should enable their graduates to make key contributions to the UK Ministry of Defence's 'Smart Procurement Initiatives' designed to improve the efficiency of defence equipment acquisition.

1. Introduction

Systems Engineering is emerging as a new discipline in response to the increasing scale and complexity of modern defence and civilian systems. Major projects now involve many different technologies with critical interfaces between them, and they also have important man–machine interfaces with customers, operators and support staff. Although there are many natural systems studied by ecologists, Systems Engineering is concerned with man-made systems designed and constructed to serve some pre-designated purpose or function at the minimum possible cost. Any system must be bounded so that it can be considered as an entity, but it cannot be completely isolated from its environment and must interact with other systems across its boundary.

In order to accomplish its purpose, a large system is generally composed of a set of interdependent and inter-related subsystems, assemblies and components which all interact synergistically to provide the 'emergent properties' by which the whole system is more capable than the sum of its parts. Each subsystem has lateral communication to 'sibling' subsystems at the same hierarchical level, downward connections to dependent subsystems, and upward connections to larger over-arching 'parent' systems. Hence 'one designer's subsystem is another's system'.

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For example, an aero-engine designer may regard his engine as a system for which the subsystems are the intake, fan, compressor, combustion chambers, turbine and exhaust. But the designer of a transport aircraft may perceive the aircraft itself as a system and the aero-engine as one of its principal subsystems. Actually, the aircraft is part of a larger air transport system incorporating airports, navigation systems, market regulation and ground transport, as well as economic, social and environmental issues.

The engineers in charge of systems at different levels can sometimes have very different perceptions and priorities, and in such cases the internal interfaces do not function well and the overall system does not operate effectively (if at all). A primary purpose of Systems Engineering is to create and disseminate a clear perception of the functionality of the over-arching system, and hence to ensure that the interfaces between its subsystems and between the system and its environment are well-organised and efficient.

Systems Engineering makes a key contribution to the design of all large and complex systems, either implicitly through the educated experience of the chief engineer or explicitly through modern paradigms and procedures. In either case, successful design in a challenging project demands the solution of a variety of problems, spanning several technical disciplines and affecting the project's operational and financial characteristics. The optimal solutions to such problems depend in turn on the scientific and technical knowledge of the engineers involved, on their skill in analysing relevant technical and operational data, and on their ability to communicate effectively with each other and also with other, non-technical stakeholders. Systems Engineering is equally important for military and civilian systems, but has been given a higher profile in military projects many of which exhibit considerable complexity. An air defence system, for example, typically involves the integrated operation of airborne and ground radar equipment, long-range interceptor aircraft (supported by air–air refuelling) and their missiles, medium-range and short-range surface-to-air missiles, plus communications, electronic warfare and command & control systems. The Defence Engineering Group's definition states that

> Defence Systems Engineering is the integration of those engineering, analytical and management activities necessary for the procurement and operation of large and complex defence systems. It promotes the achievement of performance, timescale and cost targets in the uncertain environment of rapidly-advancing technology and changing domestic and foreign policies.

A definition for civilian systems engineering would probably put less emphasis on changes in geopolitics, and more on developments in the global economy and in social attitudes.

The Defence Engineering Group's definition of defence systems engineering reflects the policy in the UK's Ministry of Defence (MoD) of allocating responsibility for directing a defence project to a single individual (civilian official or Service officer). This individual must direct all aspects of the project to deliver a system having the desired military capability within the planned timescale and cost limits. In other organisations, that responsibility may be split between

> the Systems Engineer who is responsible for the systems technical effectiveness and integrity, for risk management, for test and evaluation, and for the system's deployment to its operational environment, and
>
> the Project Manager who is responsible for planning and budgeting, and for the timely delivery of a cost-effective system to the customer's satisfaction,

but in all cases the two must collaborate closely.

2. The Defence Engineering Group

In 1991 the MoD, following a competition, established the Defence Engineering Group (DEG) at University College London (UCL).The specified objectives of the DEG were to

1. provide post-graduate education and training in defence systems engineering for engineers from MoD and its Agencies and from other organisations in the defence sector, in UK and abroad
2. establish a centre of excellence for the study of issues relevant to defence engineering and defence acquisition.

The MoD specified the original syllabus to ensure that graduates of the DEG had a good understanding of all the military technologies, of the analytical and management methods appropriate to defence projects, and of the political, military and financial environment within which defence projects are conceived and implemented. The graduates' enhanced understanding of all these areas should enable them, when they reach positions of great responsibility, to be more successful than their predecessors in completing the acquisition of defence projects successfully.

The DEG now comprises a small group of UCL academic staff (Professors and Lecturers), some Research Fellows working on contract research for the MoD and the UK defence industry, a diverse group of Ph.D. students generating doctoral theses on different aspects of defence systems engineering and acquisition, and an officer on detachment from MoD to assist the development of the DEG's courses and to provide management support for MoD students.

3. The DEG's Master of Science courses

At present the DEG provides three Master of Science (MSc) degree courses in

Defence Systems Engineering
Defence Systems Acquisition
System Test and Evaluation.

Each of the courses has the same five-module structure comprising three taught modules of lectures, a group project module and an individual project module. Each of the taught modules includes six elements, involving a week of lectures, seminars and case studies. All students take the Systems Framework and the Systems Management modules; the third taught module and the projects taken by each student reflect the different emphases of their M.Sc. degree courses. While most of the students complete their chosen M.Sc. course in one academic year, the modular course structure makes it practicable for students to undertake the course on a part-time basis over 2 or even 3 years.

The Systems Framework module contains elements required by *all* engineers in the MoD and its supporting Agencies, and in the industry supplying defence goods and services. These elements are

Defence Environment	Systems Engineering
Quantitative Methods	Operational Analysis
Cost Forecasting	System Risk

These elements provide an overview of the financial and military environment within which defence equipment is procured and operated, an introduction to the principles of Systems Engineering, and an appreciation of the analytical methodologies which help to guide the managers of defence projects.

The Systems Management module, which is taught by the Management Centre of King's College London, consists of

Organisational Analysis	Management Behaviour
Management Accounting	Corporate Finance
International Economics	Law and Contracts

These elements provide insights into the management of human resources in large organisations, the ability to interpret financial information, and understanding of the processes of negotiating and managing large contracts. The one-week elements cannot confer expertise in all areas of management, but they give the students sufficient understanding to communicate effectively with specialist departments in their own organisations, and also to make them aware of potential pitfalls.

The Defence Systems Engineering degree is designed for technical professionals engaged in directing and managing the life cycle of a large and complex defence system. It includes a specialist module in Systems Engineering whose elements are

System Architecture	System Processes
System Modelling	Engineering Technologies
Information Systems	Defence Systems

This module provides an overview of the key technologies used in defence systems, of the information systems which co-ordinate the operations of the defence systems, and of the Systems Engineering concepts, procedures and standards which facilitate the translation of the customer's requirement into an efficient engineering design.

The Defence Systems Acquisition degree is designed for professionals working in government and industry in the areas of equipment procurement and logistic support. The specialist Systems Acquisition module includes elements covering

Project Management	Collaborative Projects
Reliability & Maintainability	Logistic Support
Industrial Issues	War Studies

These elements provide the Service and industrial backgrounds to defence projects, guidelines on the provision of efficient logistic support, a review of the principles and practice of managing national or international development programmes and of procuring equipment off the shelf from domestic or foreign suppliers.

The System Test and Evaluation degree is designed for technical professionals (in MoD Agencies and other organisations) engaged in the testing of complex defence systems to evaluate their performance and to ensure their safety. Its elements include

Requirement Evaluation Practices	Test and Evaluation
Execution of Test and Evaluation	T & E Case Studies
Synthetic Environment Management	Facility Management

This module presents the best modern international practice in system test and evaluation, and indicates how the process can be accomplished most efficiently.

The three taught modules are presented in the first seven months of the academic year, roughly from October to April, ending with a formal examination in each module. Then the students, in groups of 4–6, undertake group projects linked to their degree specialisms. Each group project addresses a real current issue, such as the management of software-intensive projects, which is suggested and monitored by an interested 'sponsor' in government or industry. This activity allows the students to experience working in non-hierarchical teams, to evolve group management styles, and to demonstrate their mastery of systems engineering by subdividing their project into coherent subtasks and later integrating the results of those tasks (the latter generally proves more difficult). The group project concludes with a written report and an oral presentation to the project's sponsor and to DEG staff.

Group projects last about 2 months, and are followed by individual projects in which single students take full responsibility for tasks proposed by sponsor organisations. Such tasks are normally done away from UCL in the sponsor's own factory or laboratory, in UK or abroad. The individual projects allow the students to demonstrate their personal capabilities in planning, organising and executing a discrete mini-project with its own set of problems and risks. An individual project, like a group project, concludes with a written report and an oral presentation by the student.

Group projects often address management-related problems, such as the special features involved in managing software-intensive or international-collaborative projects. Individual projects generally address technical issues, such as

combat system design methodologies,
communication protocols and network security,
operational maintenance in an oil refinery, and
safety-critical software verification.

Because each of the M.Sc. courses presents a broad range of studies and develops (via case studies, assignments and debates) the students' abilities to analyse and present arguments, they have similarities to some modern MBA courses. However, the DEG's M.Sc. courses are arguably more demanding because they include the key military technologies and the principles of systems engineering, as well as features of the traditional MBA syllabus.

4. Smart procurement

In 1998, in response to a well-publicised series of delays and cost overruns on major defence projects, the MoD introduced a set of Smart Procurement Initiatives to make defence procurement 'faster, cheaper and better'. One of the key Initiatives is the formation for each major project of an Integrated Project Team (IPT) including empowered representatives of all the principal stakeholders, such as

the operating Service,
the procurement organisation (DPA in the UK),

the logistics organisation,
the major industrial contractor(s)

and also including representatives of specialist branches concerned with budgeting, safety, contracts, etc. An IPT will, thus, bring together all the diverse tribes in the defence community, and should promote more-coherent project management without the mutual antagonisms and misunderstandings which have plagued earlier projects. It is therefore important that the IPT leader and many of his team should have benefited from an education in systems engineering, so that they can appreciate all the issues affecting the acquisition process and can communicate effectively with all the myriad interests and cultures represented on the IPT. It is also important for others (officers, officials, executives and engineers) who are outside the IPT but interact with it to have enough appreciation of systems engineering so that their contributions to the project facilitate its success.

5. Concluding remarks

Systems Engineering is making an increasing contribution to the success of large and complex defence projects. The education of systems engineers at UCL is a demanding and multi-disciplinary process, which integrates analytical and management skills with traditional engineering disciplines. Such education is an essential part of the career development of those engineers destined to direct major defence equipment projects.