Engineering Studies, 2013
Vol. 5, No. 2, 160–173, http://dx.doi.org/10.1080/19378629.2013.795575

Routledge
Taylor & Francis Group

Discourses of systems engineering

Usman Umar Akeel and Sarah Jayne Bell*

Civil, Environmental and Geomatic Engineering, UCL, Gower St, London WC1E 6BT, UK

(*Received 2 January 2012; final version received 26 March 2013*)

Systems engineering is unique in being characterised by its methods rather than its artefacts. Consequently, the scope of systems engineering is difficult to define. While some systems engineers contend that systems engineering is capable of addressing socio-technical problems, including climate change and terrorism, others argue that it is strictly a technical field. The paper presents the results of a discourse analysis of systems engineering textbooks, journal articles, and a qualitative questionnaire administered within the International Council on Systems Engineering United Kingdom Chapter and University College London Centre for Systems Engineering. The analysis finds three parallel accounts of systems engineering in the sampled community. These representations are of systems engineering as something new, as good engineering, and as a meta-methodology. The three distinct discourses of systems engineering diverge on its concept, origin, scope, role, training, epistemological positions, and worldview. The paper shows that claims for and against the wider applicability of systems engineering techniques to complex socio-technical problems not only chart alternative courses for the future of the field but are also grounded in particular constructions of its origins, practices and worldview. While this brings circumspection to the recent rise to prominence of systems engineering within broader engineering discussion and debate, it also provides an opportunity for reflexivity within the field as it responds to demands for integrated solutions to complex socio-technical problems.

Keywords: systems engineering; discourse analysis; engineering epistemology; engineering methodology; socio-technical systems

Introduction

Systems engineering is concerned with the design and delivery of large, technical systems and products.[1] It involves the management and integration of discrete technologies to achieve higher-level objectives. Systems engineering is most commonly associated with aerospace, computer and software engineering, but its methods are increasingly applied in other domains. Systems engineering is associated with 'systems thinking', which is seen as important in addressing complex engineering problems consisting of many different interacting elements. 'Systems thinking' is an attractive alternative to reductive approaches that have been blamed for failures of conventional engineering to address the relationships between technical, social and ecological systems in the challenges of sustainability and social progress.

*Corresponding author. Email: s.bell@ucl.ac.uk

[1]Daw, "Systems Engineering," 2008; Haskins, "A Systems Engineering Framework for Eco-industrial Park Formation," 2006; Hitchens, *Systems Engineering*, 2007; INCOSE, *Systems Engineering Handbook*, 2004; ISO/IEC, *Systems Engineering*, 2002; Ring, "Applying Systems Engineering to the Enterprise," 2005.

Systems engineering is distinct in consisting of a series of methods that in theory can be applied in almost any domain. It aims to integrate the outputs of conventional engineering disciplines such as mechanical, software, electrical, structural and so on, to deliver complex technical products. Systems engineering also addresses the needs of users and the management of engineering processes, and hence pays attention to some of the social elements of delivering complex technical systems.

Systems engineering has come to wider prominence recently, with increasing emphasis on systems thinking and methods in engineering education, professional development and practice. It holds the promise of a set of principles for integrating engineering design to counter the trend towards isolated specialist engineering knowledge, and as the means for engineering to contribute more fully to solving complex socio-technical problems.

Systems engineers themselves vary in how they conceive of the field and the scope of its application. Some maintain that systems engineering methods are effective in understanding and managing a range of social problems including policing, health care, climate change, and terrorism.[2] Others are more sceptical about the role of systems engineering not only as a panacea to managing complex technological projects, but also as adequate for addressing human and social systems.

Given recent emphasis on systems engineering within wider debates about engineering skills, knowledge and contributions to society, this paper sets out to analyse how systems engineers themselves address these issues within their field. This has important implications for how other engineers and stakeholders engage with systems engineering and systems engineers. We investigate the discursive construction of systems engineering in text books, professional journals and through a qualitative survey of systems engineering practitioners and students. The methodology is outlined in detail before describing the three emergent discourses – systems engineering as something new, good engineering and a meta-methodology for generic problem-solving. The discursive deconstruction of systems engineering shows that differences within the field go beyond debate about its future direction and point to more fundamental diversity in understanding about the nature and origins of the field itself.

The rise of systems engineering

Systems engineering evolved from the management and integration of large technological projects. It is said to have been practised in the early 1940s by Bell Telephone Laboratories to manage the increasingly complex telephonic network of its parent company AT&T, and to conduct multifaceted research and development.[3] At the time, the company was not only facing an increased complexity in product management, but was also involved in military radar development.[4] Hall identifies increasing product complexity, expanding consumer needs, rapid expansion of business environment, and acute shortage of scientists and technicians as likely triggers for the introduction of systems engineering in Bell Labs.[5] Perhaps due to the achievements of the laboratory such as the invention of the transistor in 1947, development of the solar cell in 1954, and launching of Telstar I communication

[2]Hitchens, *Systems Engineering*, 2007; Mackey et al., "The Role of Systems Engineering in Combatting Terrorism," 2003.
[3]Züst and Troxler, *No More Muddling Through*, 2007.
[4]Adams and Mun, "The Application of Systems Thinking," 2005.
[5]Hall, *A Methodology for Systems Engineering*, 1962.

satellite in 1962, other industrial organisations began to adopt systems engineering methods in managing their activities.[6]

One such organisation to apply systems engineering was the National Aeronautics and Space Administration (NASA) with its Apollo Spacecraft Project. In July 1960, the Apollo Project was announced by NASA officials as having the goal of taking humans to the moon and bringing them back safely to Earth.[7] The unprecedented success of Apollo 11's moon landing in July 1969 is well documented. Whether this great success resulted from the application of systems engineering remains a topic of debate, although some systems engineers staunchly believe Apollo's success would not have been achieved without systems engineering.[8] This claim is partly supported by the later development and codification of systems engineering practices within NASA. The Administration first published the *NASA Systems Engineering Handbook* in 1995, which is widely used outside the organisation as a reference for standard methods.[9]

More recently, systems engineers have claimed that their method and approach transcends the manufacture and development of large technical projects. Some maintain that systems engineering methods are effective in understanding and managing a range of social problems including policing, health care, eco-industrial parks, climate change, and terrorism. Following the September 11 attacks in the USA, six members of the Anti-Terrorism International Working Group convened a special panel at the International Council on Systems Engineering (INCOSE) secretariat in Las Vegas. This led to the publication of a paper entitled 'The role of systems engineering in combating terrorism'.[10] The paper traces the history of terrorism, establishing it as a world phenomenon that poses a multidisciplinary challenge. It then employs systems engineering methods of requirements analysis, functional analysis, and design synthesis among others to foster likely solutions. Although the fate of the panel and its report is unclear, their confidence in the versatility of systems engineering is unmistakable.

The recent ascendance of systems engineering within the wider engineering community corresponds to an increasing interest in 'systems thinking' in engineering education and practice. 'Systems' are seen by many within engineering as the antidote to the 'silos' of conventional disciplines. Increasing specialisation and isolation in engineering is thought to contribute to failures and inefficiencies in engineering projects, reduce opportunities for innovation and undermine the capacity of the profession to deliver solutions to complex problems such as sustainable development and climate change. In 2007, the British Royal Academy of Engineering published a document 'Creating systems that work: Principles of engineering systems for the 21st century' outlining the importance of systems engineering for all engineers.[11] According to the RAEng, recent changes in society and the increasing complexity of technical systems mean that, '[w]hile it may still be appropriate for engineers to specialise in one discipline, they need in addition to appreciate how their specialism contributes to the bigger system'. This is to be best achieved by all engineers, through education and professional development, having an understanding of the principles of 'integrated systems design', which originate in systems engineering.

[6]Alcatel-Lucent, "About Bell Laboratories," 2013.
[7]Brill, "Systems Engineering," 1998.
[8]Hitchens, *Systems Engineering*, 2007.
[9]Shishko, *Systems Engineering Handbook*, 1995.
[10]Mackey et al., "The Role of Systems Engineering in Combatting Terrorism," 2002.
[11]Elliott and Deasley, *Creating Systems that Work*, 2007, p. 6.

Others within and outside systems engineering are more circumspect in their assessment of the broader utility of systems engineering methods. In an address to members of the Aerospace and Electronic Systems Society in March 1969, NASA Administrator Bob Frosch remarked that overindulgence in systems engineering techniques and procedures leads to the erosion of competence, enthusiasm, and talent, which are essential for the success of any complex project.[12] Critics of systems engineering such as Ottens go further in defining the limits to its application. Ottens contends that 'the current conceptual framework used in systems engineering is not fit for the practice of designing and managing sociotechnical systems'.[13]

This lack of consensus about the scope of systems engineering led Emes et al. to suggest an identity crisis in the field.[14] They maintain that systems engineering community is facing an identity crisis as practitioners are constantly changing roles, thereby making the community confused over its purpose. Furthermore, they claim that confusion about the identity of systems engineering is fuelled by the existence of overlapping disciplines such as operations research, industrial engineering and so on, which share the same ancestral origin as systems engineering. They suggest the need to brand systems engineering strategically within the landscape of these related disciplines. However, Arnold, commenting on the varying views about systems engineering claims that a paradigm transition has been at work.[15] He reasons that views identified with traditional systems engineering are gradually being replaced by more fluid approaches as the nature of problems changes in complexity. It is this change, in Arnold's opinion, that accounts for the obvious lack of consensus bedevilling systems engineering.

The anxiety over a lack of consensus points to alternative constructions of systems engineering within the professional community. Systems engineers themselves hold different positions in response to claims from within and outside the field regarding its utility in addressing complex socio-technical problems. These different standpoints emerge as distinct discourses within systems engineering. The discourses of systems engineering show divergence not only with regard to the future direction of the field, but also in more foundational issues such as its origin, epistemology, and worldview.

Methodology

This study involved grounded discourse analysis of systems engineering texts and questionnaires completed by systems engineers who were members of the UK branch of INCOSE or UCL Centre for Systems Engineering (UCLse). Ten textbooks (coded TB), 27 articles from the *Journal of Systems Engineering* (coded JA) and 12 questionnaires (coded QA) were analysed. Initial analysis of the data led to the basic coding categories – concept, origin, scope, role, training, epistemology and worldview. Within these, three distinct discourses of systems engineering emerged – systems engineering as something new, as good engineering and as a problem-solving paradigm.

The selection of textual data for the study was guided by relevance sampling, which is aimed at selecting only those textual units likely to contain answers to research questions.[16] It is important to note that textual units resulting from relevance sampling are not representative

[12]Frosch, "A Classic Look at Systems Engineering," 1993.
[13]Ottens, "Limits to Systems Engineering," 2010, p.110.
[14]Emes et al., "Confronting an Identity Crisis," 2006.
[15]Arnold, *Transforming Systems Engineering Principles into Integrated Project Team Practice*, 2008.
[16]Krippendorff, *Content Analysis*, 2004.

of the whole universe of texts; they simply represent a population of relevant texts. However, because it is done from different sources and authors (as in the case of books and journals), relevance sampling of texts maintains a variety of opinions needed in a qualitative research of this kind.

The qualitative method of data collection was used because it has been shown to be effective in sampling the perception of people or community.[17] Relevant information was extracted from the various sources of data and stored for analysis. The relevance of text was measured based on its reference to the origins of systems engineering and to the claim of its versatility. This was significant to the study as it provided a good deal of material with which to explore the common thread running through the data. In addition, care was taken to ensure that the articles pulled out were spread across time, and the journals available dated from 1998 to 2010.

An important data-collection instrument used in this study was the qualitative questionnaire. The questionnaire was designed to generate data from practicing systems engineers. Ten questions featured in the questionnaire ranged from those seeking personal details of respondents to establish their qualification through to those asking more specific issues of the study. The open-ended questioning approach was adopted to allow respondents to express their thoughts without any restrictions. At least one question was posed to elicit an appropriate response for each of the data required. For example, to sample opinion of systems engineers on the versatility of systems engineering, the two questions asked were: 'Do you think systems engineering methods can be employed in managing complex socio-technical systems such as policing, health care systems, etc.?', and 'Do you know of an example where systems engineering was used in managing a socio-technical system? Was it successful? Were there any limitations?'

To effectively analyse the data generated from the sampling, discourse analysis method aided by the use of QSR N6 software was adopted. Discourse analysis is an interpretative research process which views language as a social action and a framework for making sense of the world.[18] Language is thought of as culturally and socially situated, shaping the nature of reality for its users.[19] Strategies for discourse analysis involve various means such as the traditional inductive process of identifying categories or themes in collected data and then linking them in a hierarchy to search for commonality and differences. Discourse analysis culminates in the systematic linking of accounts and arguments to the perspectives from which they emerge, and possibly naming the interpretative repertoire.[20] This strategy proved useful in the analysis of data for this research.

The whole process can be seen as a three-phase activity. Phase one involved the analysis of accounts as represented in the texts. This process simply reviewed and identified themes within the data. The second phase identified regular patterns in the variability of accounts; i.e. recurring descriptions and arguments. Phase three consisted of identifying the underlying assumptions guiding a particular discourse. Also, it involved establishing a meaningful relationship among identified themes within the discourse. The identification of themes and categories in the study involved a priori and inductive coding. A priori coding concerns marking segments of data with codes already developed before examining the data, while

---

[17]Blanche et al., *Research in Practice*, 2006.
[18]Wetherell et al., *Discourse Theory and Practice*, 2001.
[19]Fealy and McNamara, "A Discourse Analysis of Debates Surrounding the Entry of Nursing into Higher Education in Ireland," 2007.
[20]Talja, *Analyzing Qualitative Interview Data*, 1999.

inductive coding involves developing codes directly from the examined data. The a priori codes used in the study which came from the research objectives were ‘origin’, ‘scope’, ‘role’ ‘epistemology’ and ‘worldview’. These codes were entered into the database of QSR N6 software as categories and were used to mark various segments of the data. The inductive codes derived directly from the examined data were ‘concept’, ‘training’, ‘technical’, ‘socio-technical’ and ‘problem-solving’.

Something new

System engineering as ‘something new’ presents it as ‘a relatively new discipline …’ [TB 3] that is preceded by a great many engineering disciplines and endeavours. The discipline is represented as having ‘originated in the fifties and sixties in the large military and space development program’ [JA 22]. Reference to World War II and the space program is not simply a matter of historical significance, but also an issue of showcasing the strong link between systems engineering and these heavily technological endeavours. There is a subtle allusion to the influence of these great events on the evolution of systems engineering. Interestingly, the narratives also convey the absence of systems engineering prior to the 1940s. Thus, it is not only implied that before 1940 systems engineering did not exist, but also that the two great events of World War II and the space program of the period were prime triggers. This has the effect of portraying systems engineering as a technical effort which evolved due to the exigent technological demands of the time.

The scope of systems engineering in the ‘something new’ discourse is restricted within the purely technical domain. This depiction is manifest in the discussion of the strengths and limits of systems engineering. Systems engineering is constructed as effectively concerned with technical and engineering activities. The discourse stresses the application of systems engineering to technological and engineering developments as ‘systems engineering has been in the domain of the technical community’ [JA 22].

Emphasis is given to the technical nature of systems engineering not only by unequivocal assertions as in the above example, but also by the construct of a distinctive and privileged technical language, for instance ‘Systems engineering has strength in left shift and the technical/engineering elements of life-cycle management’ [QR 7]. Systems engineering is presented as a unique and powerful engineering discipline which is focussed specifically on complex technical projects and problems, with almost no mention of social or contextual issues.

The systems engineer is described as performing a technical role. This perspective of a systems engineer’s role is necessary to maintain the concept of novelty and distinctiveness espoused in the ‘something new’ discourse. Systems engineers ‘design the overall system architecture and the technical approach … to ensure that the different system attributes are appropriately weighted when balancing the various technical efforts’ [TB 5]. They are also described as:

> … professionals who practice in the nexus between professional civil engineer in the transportation or the professional biomedical engineer in healthcare … or the broad group of stakeholders …, whose brokerage enables contemporary engineering projects to be brought to fruition [JA 2].

Proponents of systems engineering as something new delineate the training requirements of a systems engineer in terms of formal academic training or tuition. This is significant for its portrayal as a specialised field. One author writes that in ‘1950, a first postgraduate course about the subject (systems engineering) was created in the MIT' [JA 6] reinforcing the view of systems engineering as a mid-twentieth century phenomenon. In addition, it elicits an understanding of a possible co-evolution of the discipline with its academic training. It portrays systems engineering as a specialised field requiring some advanced academic training, and its association of the course with MIT suggests an inherent technological relevance of systems engineering.

Furthermore, in the systems engineering as 'something new' discourse, prominence is given to mathematical models for testing hypotheses regarding the behaviour of systems. This epistemic position can be characterised as empiricism, which emphasises the role of evidence and sensory perception – that knowledge can be gained through experimental observation. For instance,

> the technique of modelling is one of the basic tools of systems engineering . . . Many unknowns are singled out for examination and resolution . . . usually accomplished through a series of critical experiments involving simulations . . . [TB 5].

Similar to the above portrayal of systems engineering epistemology, the design of projects or systems is shown to be consistent with classical scientific approaches, as systems 'can be analysed and designed using standard scientific and engineering approaches' [JA 23]. This tendency to restrict systems design to the conventional methods of scientific and engineering procedures is aimed at maintaining the 'something new' discourse of systems engineering as a technical field.

To identify the worldview of the 'something new' discourse, attention was directed at how problems are generally conceived, especially on the narration of the need for systems engineering. The 'something new' discourse perceives problems as hard, tangible things that require equally hard, tangible solutions:

> . . . the German V1 and V2 missiles and especially the atomic bomb required revolutionary advances in the application of energy, materials and information. These systems were complex combining multiple 1technical disciplines and their development posed engineering challenges beyond those that had been presented by their more conventional predecessors . . . Systems engineering as we know it today, developed to meet these challenges [TB 2].

This worldview also recognises the achievement of some objectively stated goals as being a prerequisite for the effective application of systems engineering. This is a significant dimension added to the need for systems engineering which indicates thinking in the hard physical sense, the so-called hard systems thinking. Systems engineering's approach to problem-solving is represented as goal-directed, where objectives are clearly defined at the outset.

In sum, system engineering as a 'something new' discourse presents the field as a distinct set of methods and techniques that emerged during World War II and rapid technological developments that occurred in the following decades. Systems engineering is presented as a unique and powerful engineering discipline which focuses specifically on complex technical projects and problems, with almost no mention of social or contextual issues. The systems engineer is a technical expert involved in the design of the overall systems architecture and the technical approach to the project. As such, systems engineers require specific training, usually through a postgraduate university qualification, to learn the required techniques and methods. This narrative of systems engineering emphasises the role of simulation, experimentation and mathematical modelling, resting on a largely empiricist epistemology. Systems engineering as a 'something new' uses 'hard engineering' techniques to solve technical problems.

Good engineering

Systems engineering in the 'good engineering' discourse incorporates both technical and non-technical factors. Systems engineering is conceived as following due process or standard procedures expected of all established engineering endeavours – doing the right engineering to achieve the right outcome. 'Systems engineering . . . are well understood conventional engineering activities . . . often pursued by engineers and technicians . . .' [TB 3].

Systems engineering is not new, but conventional engineering done properly. In the view of one respondent, 'Systems engineering is about good engineering' [QR 1]. The respondent's subsequent discussion of systems engineering's ability to address socio-technical systems in the questionnaire shed light on his idea of good engineering. 'Many of SE techniques can be applied to these types of systems. In fact, many of the techniques originally came from the socio-technical field of systems thinking, operational research and related fields' [QR 1].

In this discourse, systems engineering is traced as far back as the beginning of engineering practice. It is often construed as not having a specific date and/or place of origin. This representation of systems engineering is significant to its depiction as good engineering. 'No particular date can be associated with the origins of systems engineering. Systems engineering principles have been practised . . . since the building of the pyramids . . .' [TB 5].

The implication is that as long as there has been engineering practice, there has been systems engineering. This claim is also corroborated in one of the journal articles: 'The search for the origin of systems engineering takes us back to the first humans that tried to build a building' [JA 8].

The scope of systems engineering in the systems engineering as good engineering discourse can be distinguished by its embrace of both the technical and social aspects of engineering. Systems engineering is represented as extending from the technical community, where system development takes place, to the social context, where the engineered systems operate. However, the discourse represents systems engineering's scope of the social context to be defined by the extent to which the engineered system is recognised as influencing (or influenced by) society. Consider the following text: 'The problems generally cannot be solved by the development of a single product or service. Instead what is involved is an arrangement of people and things, with concomitant material . . .' [TB 4].

The view of systems engineering as inclusive of the social context is re-echoed throughout the discourse of 'good engineering'. In some instances, a listing of some aspects of the social context worth considering in product development is made:

> Systems engineering . . . deals with the analysis of and design, the operation, and the maintenance of large integrated systems in a total lifecycle perspective. It takes into account technology, management, legal aspects, social and environmental issues, finance and corporate strategies to shape the total systems [JA 22].

The message is clear; systems engineering as 'good engineering' must attend to the effects of its products and services on the society. It is shown to take into account a wide range of issues including finance and environment as they affect system development.

The role of the systems engineer in the 'good engineering' discourse is not distinguished from that of a good engineer. Rather, the discourse repeatedly emphasises the systems engineer's role to be what is expected of every engineer, although it mentions brokerage between engineering and social fields.

> The systems engineer or practitioner creates systems in a structured, ordered way . . . The systems practitioner is concerned essentially with the conception and design of two types of

system; the application system, to be delivered to a customer; and the engineering system required to produce that application system. Systems engineering as a discipline seeks to provide application systems to customers and users which meet their needs, and which can be operated and maintained effectively throughout their intended life ... [TB 9].

Although it recognises formal academic training, the good engineering discourse of systems engineering lays more emphasis on experience. As one respondent to the questionnaire explains 'systems engineering comes with experience, they are not born and cannot be trained in a school environment and let loose' [QR 4]. Within this discourse, it is inconceivable that good engineering skills can be acquired within the confines of an academic institute without resort to post-academic experience. Even the training required of a systems engineer is represented as being deeply buried in science and engineering. Systems engineering training is thought of as a kind of rediscovery of ideal engineering skills.

The following characteristics are commonly found in successful systems engineers; they enjoy learning new things and solving problems; ... they are sceptical of unproven assertions; ... they have solid background in science and engineering. [TB 5]

In response to the question 'How did you become a systems engineer?' one participant answered, 'I have been one ever since I have been an engineer' [QR 8]. This clearly shows that proponents of the good engineering discourse do not consider any form of specialised training as necessary for becoming a systems engineer.

Interestingly, the epistemological position discernible in the good engineering discourse includes both empiricism and rationalism. The empirical position is represented as stemming from allegiance to conventional engineering practice, while the rational stance is shown as taking root from its unceasing appeal to common sense. However, significance is given to rationalism with emphasis on a priori truths and experience. There is a lot of reference to 'common sense', 'good judgment', and 'reason'. This position is significant in order to maintain the claim for good engineering.

Many systems practitioners do not believe that systems engineering is a separate discipline – instead they prefer to think of it as common sense. [TB 3]

In addition to overstating the value of this commonsensical approach of systems engineering, the discourse succeeds in maintaining both empiricist and rationalist epistemologies. Knowledge derivation through experience and heuristics seem to recur, for example 'systems engineering relied on experientially developed principles and heuristics' [JA 21].

Similar to the 'something new' discourse, the search for the worldview in systems engineering as 'good engineering' discourse was done in the way problems and solutions are perceived. Although problems are generally presented to be fundamentally engineering issues, solutions are extended to cover the social context; thus having some elements of soft thinking. The following quote explains this further: 'The systems provided by systems engineers are open systems ... First and foremost they are open to their users to such a degree that users and technology may not be sensibly separable' [TB 9]. Thus, systems engineering as good engineering views all well-executed engineering projects as systems engineering.

In summary, the 'good engineering' discourse constructs systems engineering as not having a specific origin as such. It maintains that the discipline can be seen in any successful engineering project and traced back to the earliest human efforts at building, and in the construction of ancient monuments such as the pyramids. Furthermore, systems engineering addresses both contextual and technical issues and translates between these different domains. All good engineers might be considered systems engineers, with particular emphasis on the role of engineers in ensuring a good fit between technical solutions and social, financial or other requirements. Also, systems engineering training consists of professional experience grounded in a good understanding of basic science and engineering principles. Systems engineering knowledge is rationalist as well as empiricist, with an emphasis on 'common sense' and 'reason'. As a 'good engineering', systems engineering is concerned with both hard and soft systems.

Meta-methodology

Systems engineering as 'meta-methodology' constructs itself as a panacea to all systems issues. Systems engineering is conceived as an all-encompassing problem-solving paradigm. The discourse represents systems engineering as a methodology that is applicable to all kinds of problems in all spheres of human life – a universal method of addressing complex world problems. The concept is that as long as a system can be identified, then systems engineering as a 'meta-methodology' can be applied in designing the system.

> Systems engineering is important, vital, because it offers the prospect of creating whole systems where man can live, prosper and flourish in harmony and balance with the rest of the environment, where man sees himself as part of, not separate from, that environment. [TB 3]

And,

> . . . an enterprise, populated by human beings continually coping with changes, must be continuously adapted to and co-aligned with its situation even while being operated. This dynamic means that a priori recipes will not suffice. Only the practice of systems engineering, real time, and just in time, can render the help needed. [JA 16]

In response to a question about the strengths of systems engineering, one participant replied:

> Potentially limitless, when used within a problem-solving paradigm. It is not a management method, but a means of creating tangible solutions to problems that can promote social harmony, preserve and protect environments. [QR 6]

Thus, it is to be inferred that all problems can be tackled as long as they are represented in this kind of generic framework.

The scope of systems engineering in the 'meta-methodology' discourse transcends familiar boundaries. Systems engineering is presented as a 'wide church' that accommodates all complex problem situations wherever they may occur. It is represented as covering problems associated with technical, social, socio-technical, and human activity systems. Systems engineering application is depicted as not the exclusive domain of the technical community, but also the concern of management organisations such as the judiciary, the police, the banks, the fire service, and so on.

The origin of systems engineering in the 'meta-methodology' discourse is narrated in a distinct way. Systems engineering is presented as having emerged eclectically from various disciplines and fields including philosophy, operations research, management, general systems theory, and so on. The discourse effectively stresses this eclectic evolution of systems engineering to foster its depiction as a generic methodology for solving problems. Date, place and/or historic figure related to systems engineering's origin are conspicuously understated.

> Many systems practitioners do not believe that systems engineering is a separate discipline – instead they prefer to think of it as common sense, although they generally concede that such sense may be far from common. Further they may well deny that systems engineering has any special methods or techniques, but is simply an attitude of mind . . . They probably would not see systems engineering as strongly related to, or emerging from, Operations Research, although every textbook on the subject will show OR as the supposed origin. [TB 9]

Systems engineers in this discourse are depicted professional 'problem solvers' who use miscellaneous tools in a generic 'meta-methodology' paradigm to create tangible solutions to all kinds of complex world problems. The discourse is guided to depict the role of systems engineers as required in all sectors of the society, small or large. '. . . systems engineering practitioners who combine sound knowledge of systems theory and methodology with important specific factors relevant to large scale private, public and societal problems extant' [JA 2]. Furthermore, systems engineering as 'meta-methodology' discourse emphasises a multidisciplinary training for the systems engineer. It shows systems engineers as required to acquire an array of skills in order to facilitate their generic problem-solving role. It is not distinct whether formal training is stressed at the expense of experience as both seem to be encouraged. The kinds of skills suggested for the systems engineers are disparate. Nonetheless, recommendations for managerial skills abound in the discourse.

> . . . a very good knowledge of the context subject, plus excellent personnel skills and social competence, a strong sense of priorities, excellent communication skills, and professional project management capabilities are the main characteristics of a good systems engineer. [JA 25]

An array of epistemological positions including empiricism, rationalism, and pragmatism are represented in systems engineering as 'meta-methodology'. These epistemic positions are shown to be relevant in knowledge derivation and explanation. This position is significant for the 'meta-methodology' perspective so that its all-encompassing scope can be realised.

> Examination of possible approaches to the . . . problem forms the second phase, analysis. The exact nature of this analysis will depend upon the nature of the system. In communications it might be information theory; in digital computers, symbolic logic; in controls, servomechanism analysis. In some fields, such as control, this phase is a highly developed one, and for the simpler systems it has become pure routine. [JA'19]

Problems, in this discourse, are conceived as a conglomeration of intricacies which call variously for hard and soft systemic interventions. The discourse presents problems in this light to highlight the universal application of systems engineering. Thus, where a problem requires purely hard system intervention, systems engineering as a meta-methodology is relevant. Similarly, for a problem that needs a soft system solution, systems engineering is still relevant as the following quote illustrates:

> In an era and in a universe where problems seem to be growing larger, more interrelated, and more complicated, systems analysis has, therefore, become the prescribed approach for where in the world is there a problem that is simple or small? [JA 15]

In summary, systems engineering as a 'meta-methodology' views the field as a universal problem-solving paradigm, superior to many, if not all, other approaches. It is applicable to all spheres of human life, including health, policing, security, and the environment. It originates in diverse disciplines including general systems theory, operations research and ancient philosophy, emphasising systems thinking and holism. The systems engineer is a general problem solver. Their training should be multidisciplinary and emphasise communications and interpersonal skills along with good knowledge of the context in which they

Table 1. Discourses of systems engineering.

Paradigm	Concept	Origin	Scope	Role	Training	Epistemology	Worldview
Something new	Systems engineering is something new; a distinct discipline; essentially technical	Originated in the first-half of the twentieth century in a heavily technological environment	Restricted within the technical community; engineering fields	Systems engineer performs basically technical roles	Formal training emphasised to acquire skills	Empiricism; lots of emphasis on classical scientific methods	Hard systems thinking; references to 'industrial products' and 'project work'
Good engineering	Systems engineering is simply good engineering; conventional engineering done properly; doing the right engineering and following 'due process'	Origin of systems engineering traced to as far back as the beginning of engineering practice; refers to Noah's Ark, Egyptian pyramids, etc.	Extends from technical fields to include social context of engineering practice	Systems engineer depicted as performing effectively in the nexus between technical and social contexts	Understates the need for formal academic training and promotes the idea of post-academic experience	Elements of empiricism and rationalism; a lot of reference to 'common sense' and 'reason'	Hard systems thinking with some elements of soft systems thinking
Meta-methodology	Systems engineering is an all-encompassing problem-solving paradigm; a universal method	An emphasis on the eclectic evolution of systems engineering; various disciplines presented as likely sources	Broadened scope as to cover all kinds of complex world problems	Systems engineer presented as professional 'problem-solvers' equipped with a generic problem-solving model	Emphasises multi-disciplinary training requirement for systems engineer	Points to knowledge methods that indicate empiricism, rationalism, and pragmatism	A hybrid of hard and soft systems thinking

are working. As a 'meta-methodology', systems engineering takes a pragmatic conception of the nature of knowledge, drawing on empiricist and rationalist epistemologies in devising generalised understandings of systems solutions to problems. Systems engineering is not only concerned with the interface between social and technical systems but is applicable to social, political and all domains of human problems. Table 1 presents a summary of the three discourses of systems engineering.

Conclusion

The three discourses of systems engineering identified in our analysis represent systems engineering as a new technical discipline; simply good engineering; and a universal problem-solving methodology. The discourses are linked by a shared concept and language of 'the system' but diverge as to where they draw the boundaries of engineering knowledge and the limits to the engineering method.

As a field that is characterised by its methods rather than its artefacts, systems engineering can seem more difficult to pin down than more established disciplines. Unlike conventional engineering disciplines, the definition of systems engineering is inherently abstract. Without recourse to a unique set of concrete outcomes which materialise the expertise of systems engineers in the way that a microchip materialises electronic engineering knowledge or a bridge classically embodies structural engineering expertise, systems engineering remains open to constant re-interpretation. The recent interpretation of systems engineering as a set of general principles for engineering design and complex problem solving has led to an increase in profile, but has also contributed to what many systems engineers experience as an identity crisis.

As a field that explicitly attempts to address the inter-relationships between technologies and the people who build and operate them, systems engineering inevitably confronts questions of the nature of modern society. The point at which systems engineering theorists and practitioners draw their own boundaries around their expertise and ability to characterise complex socio-technical problems reflects a particular professional position, evident in the three distinct discourses we have identified. These three discourses show that systems engineering is richly constructed within the field. The divergence between the relatively tightly bounded problems which the 'something new' discourse addresses or the claims to universality of the 'meta-methodology' discourse is not merely a matter of ambition or modesty. The three different discourses show distinct constructions of not only the nature and origins of systems engineering itself, but also of knowledge, expertise and society. This diversity of representation provides the possibility for critical reflexivity within the field as it responds to demands from the wider engineering community for integrated solutions to complex socio-technical problems.

References

Adams, Kevin M., and Ji Hyon (Nina) Mun. "The Application of Systems Thinking and Systems Theory to Systems Engineering." Paper presented at the 26th Annual National Conference of the American Society for Engineering and Management, Virginia Beach, VA, 2005.

Alcatel-Lucent. *Bell Labs*, 2013. http://www.alcatel-lucent.com/wps/portal/bell-labs Alcaltel-Lucent (accessed June 15, 2010).

Arnold, Stuart. "Transforming Systems Engineering Principles into Integrated Project Team Practice." Unpublished PhD diss., Cranfield University, 2008.

Blanche, Martin T., Kevin Durrheim, and Desmond Painter, eds., *Research in Practice: Applied Methods for the Social Sciences*, 2nd ed. Cape Town: University of Cape Town Press, 2006.

Brill, James H. "Systems Engineering – A Retrospective View." *Systems Engineering* 1, no. 4 (1998): 258–66.
Daw, Samuel. "Systems Engineering – The Reliable Method of Rail Systems Delivery." *Bechtel Technology Journal* 1, no. 1 (2008): 33–42.
Elliott, Chris, and Peter Deasley. *Creating Systems that Work: Principles of Engineering Systems for the 21*st *Century.* London: The Royal Academy of Engineering, 2007.
Emes, Michael, Alan Smith, and Douglas Cowper. "Confronting An Identity Crisis – How to 'Brand' Systems Engineering." *Systems Engineering* 8, no. 2 (2005): 164–86.
Fealy, Gerard M., and Martin S. McNamara. "A Discourse Analysis of Debates Surrounding the Entry of Nursing into Higher Education in Ireland." *International Journal of Nursing Studies* 44, no. 7 (2007): 1187–95.
Frosch, Robert A. "A Classic Look at Systems Engineering." In *Readings in Systems Engineering*, ed. Francis T. Hoban and William M. Lawbaugh, 1–7. Washington, DC: NASA, 1993.
Hall, Arthur D. *A Methodology for Systems Engineering*. Princeton, NJ: Van Nostrand, 1962.
Haskins, Cecilia. "A Systems Engineering Framework for Eco-Industrial Park Formation." *Systems Engineering* 10, no. 1 (2006): 83–97.
Hitchens, Derek K. *Systems Engineering: A 21st Century Systems Methodology*. Chichester: Wiley, 2007.
INCOSE. *Systems Engineering Handbook: A "What To" Guide For All SE Practitioners*. Seattle: INCOSE, 2004.
ISO/IEC 15288. *Systems Engineering – System Life Cycle Processes*. ISO/IEC, 2002.
Krippendorff, Klaus. *Content Analysis: An Introduction to its Methodology*, 2nd ed. London: Sage, 2004.
Mackey, William F., Harry Crisp, David Cropley, James Long, Stephen M. Esquire, and Shabaz Raza. "The Role of Systems Engineering in Combatting Terrorism." INCOSE 13th Annual International Symposium Proceedings, Crystal City, VA, 2003.
Ottens, Maarten M. "Limits to Systems Engineering." In *Philosophy and Engineering: An Emerging Agenda*, ed. Ibo van de Poel and David E. Goldberg, 109–22. London: Springer, 2010.
Ring, Jack. "Applying Systems Engineering to the Enterprise." Paper presented at the INCOSE 18th International Conference on Systems Engineering, Las Vegas, NV, 2005.
Shishko, Robert. *NASA Systems Engineering Handbook*. Washington, DC: NASA, 1995.
Talja, Sanna. "Analyzing Qualitative Interview Data: The Discourse Analytic Method." *Library & Information Science Research* 21, no. 4 (1999): 459–77.
Wetherell, Margaret, Stephanie Taylor, and Simeon J. Yates. *Discourse Theory and Practice: A Reader.* London: Sage, 2001.
Züst, Rainer, and Peter Troxler. *No More Muddling Through: Mastering Complex Projects in Engineering and Management.* Dordrecht: Springer, 2007.