The Influence of the Concept of Capability-based Management on the Development of the Systems Engineering Discipline

Elena Irina Neaga[1], Michael Henshaw[1] and Yi Yue[2]

[1] Department of Electrical and Electronic Engineering, Systems Engineering Innovation Centre, Loughborough University, Leicestershire, United Kingdom, {E.I.Neaga, M.J.d.Henshaw}@lboro.ac.uk
[2] Defence Science and Technology Organisation, PO Box 1500, SA 5111, Australia, Yi.Yue@dsto.defence.gov.au

Abstract

This paper explores the implications of a capability-based conceptual approach on the development of the systems engineering (SE) discipline. It deals with the identification of some potential limits and gaps of traditional SE approaches and demonstrates the need for new and innovative developments which support the concept of capability based engineering, especially as applied in the military domain and networking environments. The innovative approaches include partnership for capability planning and service descriptions for capability representations. The paper also presents a very brief assessment of the state-of-the-art of cognate domains such as capability based planning alongside requirements engineering and management, and considers the extent to which they address capability based concepts. The related concepts of system of systems (SoS) and the endeavour to extend SE to SoS are necessarily addressed.

Key words – capability engineering, system of systems, capability based planning, defence, military operation

1 Introduction

Capability is a widely used concept, especially in the military domain. It is at the heart of Systems Engineering (SE) but, unfortunately, it has seldom been addressed as the focus explicitly in traditional SE approaches.

There is a considerable amount of work on the definition and analysis of the capability concept from different perspectives such as engineering (mainly ICT), military, organisational, and managerial, alongside Through Life Capability Management (TLCM) [1-4]. According to UK MoD [5] "*capability is the enduring ability to generate a desired operational outcome or effect, and is relative to the threat, physical environment and the contributions of coalition partners*". There are several definitions of the term 'capability' and different usages of those definitions [4-7]. The term is also interpreted differently in different sectors and has even been rather broadly interpreted in the defence sector [8].

The UK MoD, together with other TTCP (The Technology Cooperation Program) partners (USA, Australia, Canada, and New Zealand), has adopted a Capability-Based Planning (CBP) approach for its management of long term military capability development. TTCP [9] describes a generic process of CBP and identifies an effective investment strategy as the outcome of CBP. In [10], Davis defines CBP as "*Planning, under uncertainty, to provide capabilities suitable for a wide range of modern-day challenges and circumstances while working within an economic framework that necessitates choice*".

This focus on capability has demanded a new approach for designing and developing or engineering a capability, which is termed Capability Engineering (CE). The term CE has been introduced by Pagotto and Walker [1] as follows: "*Capability engineering, a new methodology with the potential to support defence planning and acquisition holds promise of providing at least a partial answer to the challenges of defence transformation*." They suggested a new (systems) engineering discipline, but the above definition is incomplete and it is premature to predict the likely outcome of CE. Therefore additional studies and analysis supported by a coherent systems process definition are needed.

The NECTISE research programme has a particular emphasis on networking capabilities to facilitate advanced military operations supported by innovative SE solutions [11]. This programme deals with the problems associated with translating abstract capability concepts to tangible approaches. These problems are mainly related to architecting and/or engineering capability. The related analysis will lead to a framework that includes views of future SE developments. The new approaches will support the definition of a high level conceptual framework of military capability enabled through networking and ubiquitous and pervasive computing (services).

The main contribution of this paper is to analyse the effects of capability based management on the development of SE approaches that will have a meaningful impact on future military systems research and application, especially to provide mechanisms for the realisation of network enabled capabilities. In particular, we suggest an alternative (or

extension) to the traditional approach of baseline requirements through SIMILAR (**S**tate the problem, **I**nvestigate alternatives, **M**odel the system, **I**ntegrate, **L**aunch the system, **A**ssess performance, and **R**e-evaluate) task representation [12]. This approach supports the definition and development of the new area of (systems) engineering - CE. It also supports effective utilisation of complex systems or SoS in the battlespace and/or emergent applications which can be managed through extended development cycles corresponding to through life capability management.

2   Systems Engineering Successes and Shortcomings

This section includes an investigation of the type of problems and related methods through which traditional SE has claimed huge success and the main characteristics of the related systems. The International Council on Systems Engineering (INCOSE) fellows' consensus of SE definition is [13] "*an engineering discipline whose responsibility is creating and executing an interdisciplinary process to ensure that the customer and stakeholder's needs are satisfied in a high quality, trustworthy, cost efficient and schedule compliant manner throughout a system's entire life cycle. This interdisciplinary systems engineering process is usually comprised of the following seven tasks: State the problem, Investigate alternatives, Model the system, Integrate, Launch the system, Assess performance, and Re-evaluate. These tasks can be summarized with the acronym SIMILAR*". However some other definitions have complemented the INCOSE definition. The IEEE defines the Systems Engineering Process (SEP) as [14]: "*The SEP provides a focused approach for product development that attempts to balance all factors associated with product life cycle viability and competitiveness in a global marketplace*" .

It is either implicitly or explicitly stated in above definitions that the process will lead to a product or system, which has a life cycle, as an output. Hence, SE concerns both process and product. It is very important to note that actually SE deals with at least three perspectives. In addition to the system of focus or the product, and the SE process itself; there is also the wider system or context, where perceived problems give rise to the needs for intervention, which in turn triggers the SE process in the first place. For example, in the case of producing a nuclear submarine, the three perspectives are: the submarine itself, which is a complex physical system, the application of SE, which is a process with a series of purposeful human activities, and the modern military force, a highly complex socio-technical system.

In advanced economies there is a shift from product to product-service, and this is also true in defence (especially in UK). This has changed the business paradigm and has also introduced a new type of system to be considered and (possibly) a new approach to SE.

Generally SE has progressed from the relatively narrow paradigm of Requirements Analysis, Functional Analysis/Allocation, and Synthesis—governed by Systems Analysis and Control. The most recent SE approaches include several Process Requirements that can be grouped into the broad areas of Technical Management (planning, assessment, and control), System Design (requirements definition, solution definition), Product Realization (implementation and transition to use), Technical Support (systems analysis, requirements validation, product verification and validation), and Acquisition and Supply (Figure 1) [15].
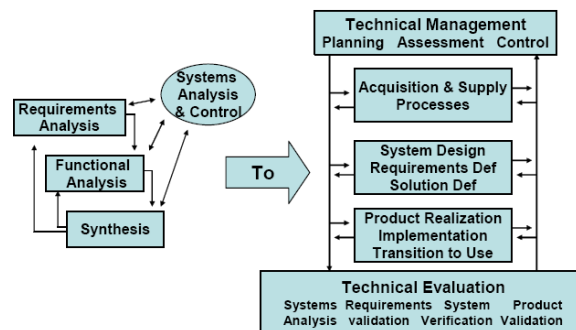

Figure 1 *Systems Engineering Process [15]*

This approach was harmonized with the even broader concept of SE included in ISO/IEC 15288: 2002 (System Life Cycle Processes). This framework further broadens SE by considering enterprise processes such as Enterprise Management, Investment Management, Systems Life Cycle Management, and Resource Management. This International Standard also established a common framework for describing the life cycle of systems created by humans. It defined a set of processes and associated terminology. These processes can be applied at any level in the hierarchy of a system's structure. Selected sets of these processes can be applied throughout the life cycle for managing and performing the stages of a system's life cycle. This is accomplished through the involvement of all interested parties with the ultimate goal of achieving customer satisfaction.

The INCOSE fellows' definition of SE does not restrict its application to physical systems such as products or product families. However, when it is extended to more complex systems, there are additional matters to be considered and clearly distinguishing the above three perspectives is very important. These will be analysed in the sections 4 and 5 which discuss CE in detail.

SE has accomplished a lot in its relatively short history. The discipline of SE has been regarded as essential in the development of complex systems. Since its recognition in 1950s [16], most mature and significant applications are in engineering domains for complex physical systems, such as in the communications industry for large scale network projects, software engineering, in aeronautics and space programs, and in complex defence platforms. INCOSE

compiled a long list of SE application profiles and systems; some are traditional domains as mentioned above; others are more speculative; and some are even left blank waiting to be developed in future [17].

A few characteristics of traditional SE as currently practised by engineers are apparent. It requires an unambiguous singular goal and emphasises early definition and validation of clear and concise requirements; desired functions are derived from these requirements, decomposed and allocated to system elements. Both the requirements and the function allocation are static over time and the solution is the optimum one which satisfies the requirements. Hitchins argues that this is not SE but the engineering of systems – creating artefacts [18]. This approach is especially concerned with functional decomposition.

Interestingly, MIT [19] has used the term 'Engineering Systems' to describe an "*emerging field of study involving large complex systems whose properties are determined not only by technology, but also by people's behaviour, plus the laws of physics and other natural sciences*". Regardless the differences in terminology, it is clear that there is a distinction between an approach based substantially on functional decomposition ('traditional' as we have termed it) and a wider perspective on systems. We have chosen to use the term 'systems of systems' [20] to describe a class of systems that introduces some important characteristics that require considerations beyond those we have termed 'traditional'.

3   Emergence of "System of Systems" Engineering

With increasing complexity brought about by greater connectivity, there are many instances when both operationally and managerially independent systems are brought together to form a new whole system to respond to arising needs. Systems belonging to this category are often termed as "System of Systems" (SoS) [20]. To combat these problems of complexity, there is emerging effort in a new branch of SE called SoS engineering.

According to Kaplan [15] SoS engineering is defined as the "*cross-system and cross-community process that ensures the development and evolution of mission-oriented capabilities to meet multiple stakeholders' evolving needs across periods of time that exceed the lifetimes of individual systems*". The progression from a subsystem to a system and finally to a SoS is illustrated in Figure 2 [22], which also explicitly considers incorporated capability.

Kaplan's definition of SoS Engineering captures the major differences from traditional SE, in that it operates across complex systems life cycles and across communities, and is concerned with the creation of capabilities rather than physical systems. The evolutionary rather than static nature is another hallmark of SoS engineering.

Although there is not a universally accepted definition of the term systems of systems, the following elements are representative of the current themes emerging for SoS and SoS Engineering [20-23]:

- The elements of a SoS have operational and managerial independence of each other. SoS display emergent behaviours and, notably, can achieve effects that are unachievable by the systems that form them when acting in isolation.
- The elements of a SoS are geographically dispersed and it is information (rather than mass or energy) that is transported between the elements. That is, networks are an important aspect of SoS.
- SoS evolve rather than being designed or created from a clean sheet.
- In the case of SoS engineering, it is inherently multi-disciplined in nature and often includes heterogeneous systems.
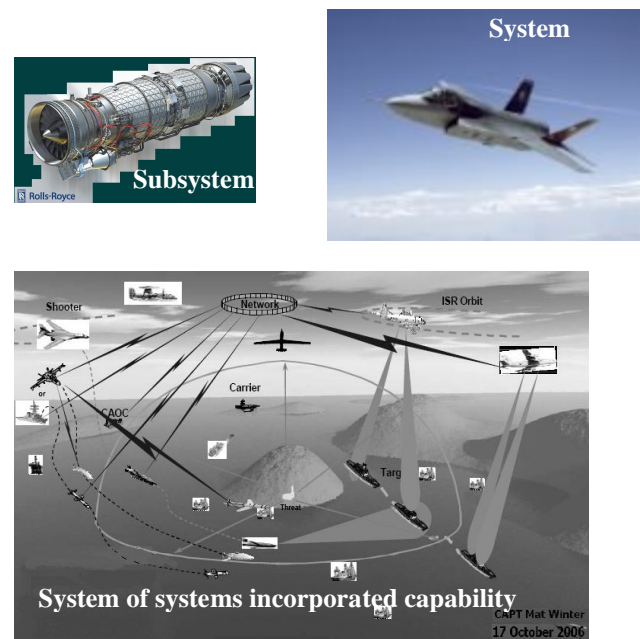

Figure 2 *From Subsystem to SoS [22]*

Since SoS almost always involves human and socio-technical systems, many of the challenges of SoS engineering arise from human, cultural and informational aspects.

Whether the concept of SoS is really different from systems and whether SoS can be approached with the traditional SE methods are matters of contention [18, 21]. The authors believe that the distinction is a helpful one, because consideration of the criteria set by Maier [20] and extended by DeLaurentis, when defining the case of an International Consortium of System-of-Systems Engineering [22-23], implies a distinct set of concerns and opportunities that the engineer must embrace. It is also very important to recognise that some of those (e.g. those concerned with multiple owners of the systems within a SoS) have much to do with non-engineering and non-scientific disciplines, such as business and finance.

4   Capability Engineering

In the defence community, the failures, cost and time overruns that have plagued complex defence acquisition projects and the realisation that systems procured for the cold war do not adequately meet the needs of today's military operations, have prompted re-examination of the way defence capability development is carried out.

CBP has been introduced as a better alternative. With capability as the core concept, the intervention strategy space is broadened beyond physical system products. Hence, from a design perspective, an holistic view needs to be taken and capability solutions considering synergistic relationships among all Defence Lines of Development (DLODs) need to be created, i.e. we must try to design in the emergent properties of the system. This is the endeavour of CE and it is more akin to System Architecting [24] than to SE.

There have recently been some efforts to model and represent capability for the purpose of understanding how it must be managed through life. Notably, the TRAiDE™ tool [25], which essentially provides an integrating environment for a number of capability-relevant tools (e.g. costing, performance, etc.), represents capability in the form of a target to enable users to conjecture on future investment needs. Kerr *et al* [7] have also proposed a unified picture for future capability that consists of a framework of three layers: effects based operations, force structures, and building blocks (facilities and platforms).

Touchin & Dickerson [26] considered the nature and essential structure of military capability and defined the distinction between the assembly of available military assets to conduct a specific operation and the longer-term business of planning for future needs. They also stressed, given the difficulty of articulating requirements for capability, the importance of a model-based approach for eliciting and capturing the real capability needs. In this context architecting for capability is crucial and it has been defined as the selection, integration and synchronisation of elements from across the DLODs, for both current and future military capability needs, and the assessment of the resulting potential to meet those needs.

Network enabled capability is the MOD's major endeavour to provide shared awareness to facilitate communication, command and management across the battlespace. New approaches of capability planning, development and management are required. Yue and Henshaw [4] proposed a holistic approach of UK Military Capability Planning as a conceptual model using the fractal principles.

Here we offer the following description of capability engineering:

A systemic design approach, with a particular military capability as the system of interest, which synthesises fundamental inputs to create a satisfying result, while considering critically moral, social, economic and political issues. It explicitly addresses changeability and evolvability.

This captures the essence of the capability centric nature and tackles head on the inadequacies of traditional SE, as discussed in section 2.

In non-military context, pervasive and ubiquitous IT, fast growth of service provision in the wider economy including manufacturing sector and changes in business strategic environment, combine to drive a need for CE, which enables evolvable capability to be architected in a highly cohesive fashion. The concept of dynamic capabilities is attracting much attention in the literature [27-30]. Teece et al. [31] conceptualised 'dynamic capabilities' as an organisation's ability to flexibly adapt and develop appropriate capabilities in a changing competitive environment. Therefore dynamic capabilities are defined as a company's abilities to integrate, build, and reconfigure internal and external competences and resources to address a rapidly changing environment. The attribute 'dynamic' refers to the ability to renew competences so as to achieve congruence with the changing business environment; and the term 'capabilities' emphasises the key role of strategic management in appropriately adapting, integrating, and reconfiguring internal and external organizational skills, resources and functional competences to match the requirement of a changing environment.

Capabilities are also manifested in typical business activities, and are not merely resources. While resources represent assets possessed by the company, capabilities are the glue that combines, develops, and transforms the resources to create value offerings for customers [31-32]. As such, capabilities are built upon the processes developed by firms, by bringing people and resources together in repeated efforts. In this manner both behaviour and ability are synthesized (i.e., not separated) in defining capabilities.

It is against this backdrop of capability focus in both military and non-military contexts that despite SE's success, there are an increasing number of researchers and practitioners voicing concerns about its current limitations in dealing with increased complexity [33-35].

5   A conceptual framework of impact of capability-based management on SE Discipline

Table 1 lists contrasting characteristics of traditional SE and CE along 8 features. The three perspectives with which CE deals are the socio-technical system of concern that needs to posses a particular emergent capability, the CE processes and the wider system in which this capability needs to be employed to achieve required effects.

Table 1 *Contrasting characteristics of traditional Systems Engineering and Capability Engineering*

		Traditional SE	CE
1.	System	Physical engineering	Socio- technical
2.	Complexity	Technical dimension	Multi-dimensional
3.	Goal	Unambiguous, singular	Changing, multiple
4.	Requirements	Well defined	Evolving and volatile
5.	Risk management	Limited	Highly adaptive
6.	Metrics	Well defined (e.g. INCOSE handbook)	Hard to define, agree and quantify
7.	Process	Well established	Learning
8.	Solution	Upfront specific	Incremental (maybe multiple)

In the military context, the wider system is the military system which applies military forces in concert to achieve military objectives and with other government and non-government agencies to achieve political objectives. It should be noted that in this system, not all elements are necessarily military force elements, e.g. some may be industry elements. In order for this system to fulfil its objectives, some particular military capabilities are perceived to be necessary, which are the emergent properties from interactions of subsets of the elements. The CE process is applied to: design, generate and evolve the capability. The relationships of these three perspectives, i.e. the capability, the CE processes and the military system, are illustrated in Figure 3. Figure 4 presents the MoD's view of the key aspects of the relationship between project systems engineering, SoS engineering, and CE [36].
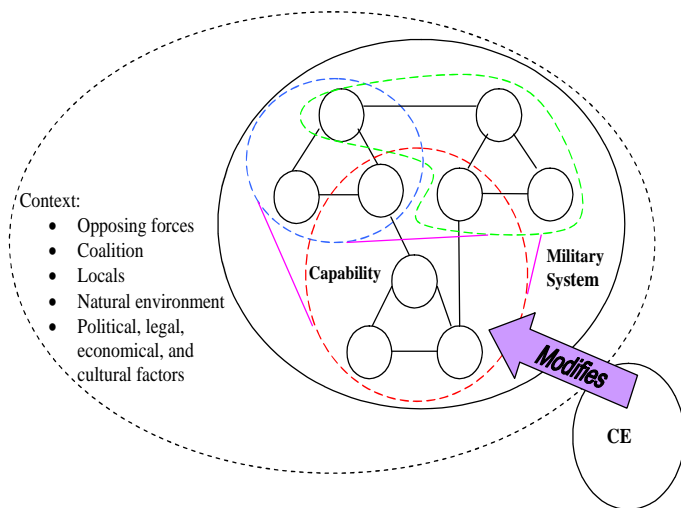

Figure 3 *Perspectives in CE and their relationships*

Traditional SE is often classified as a hard systems thinking approach, where a desired system state can be easily ascertained and articulated unambiguously. Current system state can be assessed accurately; and alternative solutions for moving the system from current state to desired state can be evaluated objectively and quantitatively to select an optimal one. Finally the optimal solution is implemented systematically and rigorously. In the problem space where CE is required, these basic assumptions no longer hold (Table 1).

5.1 Discussion

The way that the SIMILAR process may be adapted for CE is now considered and presented in table 2.

Table 2 *Adapting and comparing SIMILAR*

SIMILAR Tasks	System Engineering	Capability Engineering
Statement of the problem	Clear stakeholders and customer requirements	Ambiguous requirements, must convert a 'mess' into 'problems'
Investigate alternatives	Analytical methods	Soft systems thinking including human
Model the system	Hard modelling approaches and alternative solutions	Hard and Soft modelling approaches
Integrate	Integrated methods and systems	Dynamic process and interoperable systems
Launch the system	Deployment of the system	Evolutionary process
Assess performance	Functional performance metrics	Additional criteria
Re-evaluate	Feedback	Feedback and learning, co-evolution of a wider system

In traditional SE, "Statement of the problem" takes the form of stakeholders and customer requirements in functional or behavioural terms. It identifies what activities must be done to address the problem situation. Logically, it can be deduced that two sub-steps, goal setting and gap discovering and analysis, must be included in this stage. We would argue that, in CE because we are looking into capability rather than a defined product, goal identification is not always straight forward and translation from customer needs to problem statement is much more ambiguous. Dörner [37] presented convincing evidence of both the difficulties of goal setting in complex strategic decision making and the detrimental impacts on outcome when this was not done properly. In order to cope with added complexity in CE, to make sure we are addressing the right question [38], and to avoid fallacies associated with goal setting, it is necessary to add a sub-step to explore purpose in front of the above mentioned two sub-steps. This new sub-step will help to surface assumptions and agenda and to allow certain degrees of freedom in the problem statement, which needs to be revisited and re-

evaluated many times in later stages. To some extent we are emphasising that in CE the journey is as important as the project. Various 'soft' systems methodologies can be used to assist in the accomplishment of this [39]. Soft OR professional will see this sub-step as converting a 'mess' into problems. Another problem for CE is that system boundary judgement becomes more difficult. Partly because capability is an abstract system rather than a physical system; thus any particular component of the wider system may contribute to multiple capabilities and the interactions between capabilities

are difficult to conceptualise and understand, as shown in Figure 3. Because of the evolvable nature of SoS and because of the need to develop (change) capability rapidly, the requirements for future capability are often unpredictable and change throughout the course of the development. The focus should be achieving better understanding and preparation for intelligent adaptation to proactively incorporate changes.
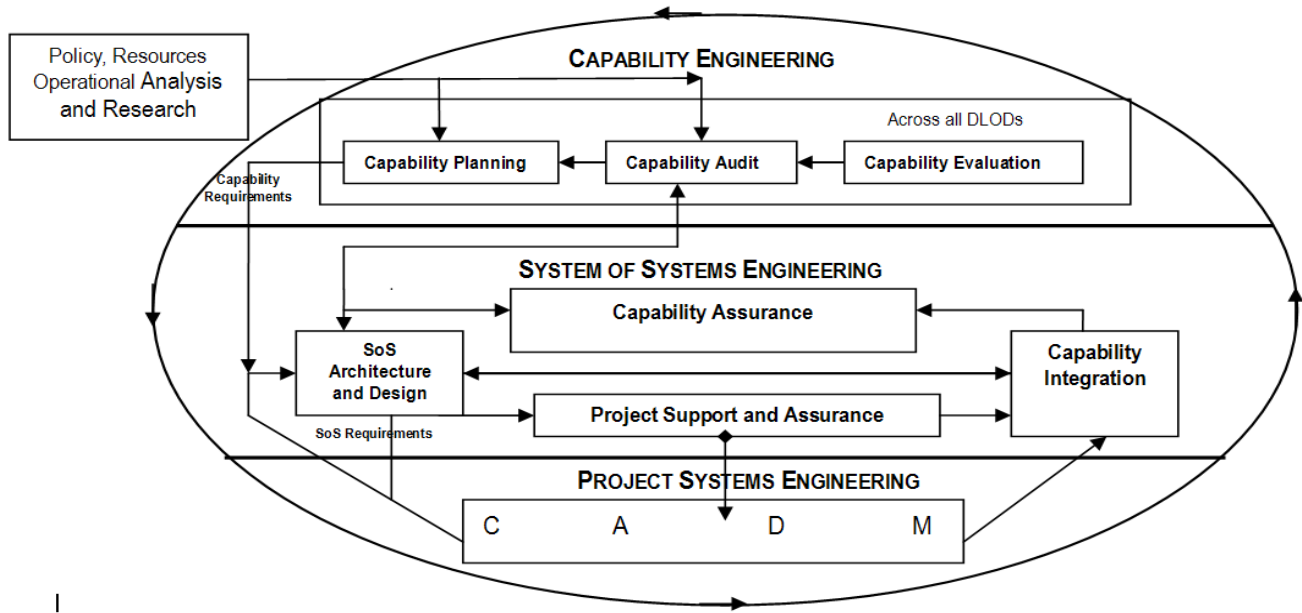

Figure 4 *The relation between CE, System of Systems Engineering and Project Systems Engineering based on [36]*

For the "Investigate alternative" stage, the capability focus of CE opens up the solution space and shifts away from purely technology and equipment focused artefact building interventions. To fill a capability gap, an holistic view will be taken and the broadest innovation will be sought. The intervention must be based on consideration across the DLODs. Whereas traditional SE will be applicable to solutions that are essentially in the equipment DLOD, CE is needed for the consideration across all DLODs. Also, to facilitate innovation and avoid anchoring the effect of current capability solutions, an idealised design should be created, where the current capability solution is not treated as a baseline but as a constraint.

"Model the system" stage creates models for alternative designs in order to evaluate them. In CE, a human can no longer be treated as just another part in a large system, hence traditional modelling approaches are inadequate. For example, appropriate representation of all DLODs in models must be addressed.

In CE "Integrate" must assume a new dynamic dimension because of the need to achieve interoperability between new and legacy systems.

"Launch the system" in CE is an evolutionary process.

In CE, there are many pairs of mutually conflicting properties of the system that need to be traded, e.g. stability vs. evolution, diversity/performance vs. affordability. Therefore, in "Assess performance" stage, in addition to functional performance metrics, additional criteria reflecting these properties must be measured.

In CE, "Re-evaluate" has a broader remit such that it does not only provide feedback between the stages, but also provides the learning mechanism that is critical for the co-evolution of the wider system with its context.

The discussion above indicates that both hard and soft systems methodologies must be applied in CE and that metamodelling approaches are needed.

Networking of capabilities and especially in the military domain has required additional approaches such as innovative systems engineering and/or SoS engineering. However these approaches do not completely cover the requirements of networking the military capabilities.

6   Conclusions

This paper provides an argument for the need to extend traditional Systems Engineering to address the problem of creating innovative results which support the concept of

capability as the system of interest. This extended form of SE is defined as Capability Engineering. Possible ways of modifying SIMILAR [12] are proposed.

This paper has established the critical foundations for including a capability based approach in the development of the SE discipline. The possibilities of extending traditional systems engineering with new approaches defined as capability engineering have been analysed. This proposal is based on gap analysis of systems engineering applied to complex military applications based on CBP, acquisition and delivery as well as realisation of the NEC concept. It is rooted in extension of the SIMILAR SE approach.

This paper also demonstrates that a new SE framework to encompass capability based management is required, reflecting the dynamics and uncertainty of SoS and the added complexity of operating in a SoS environment.

7   Acknowledgement.

8   References

[1] Pagotto, J. & Walker, R.S. (2004), "Capability Engineering - Transforming Defence Acquisition in Canada", *SPIE Proceedings series, Battlespace digitization and network-centric systems IV*, 5441, pp.89-100.

[2] DE&S UK MoD (2007), *The Systems Engineering Handbook: Principles, Practices and Techniques*.

[3] IET Forum on Capability Engineering - At Home and Abroad, 2006, UK.

[4] Yue, Y. & Henshaw, M. (2009), "An Holistic View of UK Military Capability Development", *Defence and Security Analysis,* 25(1), 53-67.

[5] Ministry of Defence (MOD), (2009) "Acquisition Operating Framework", http://www.aof.mod.uk/aofcontent/operational/business /capabilitymanagement/capabilitymanagement_whatis. htm, accessed on 26 Feb 2009.

[6] Daw, A. (2005), "On the Onion of Integration", keynote presentation to International conference on innovation and integration in aerospace sciences, Queen's University Belfast.

[7] Kerr, C., Phaal, R. & Probert, D. (2008), "A strategic capabilities-based representation of the future British armed forces", *Int. J. Intelligent Defence Support Systems*, 1(1), 27–42.

[8] Touchin, M. (2007), "System of Systems Engineering for Capability", presentation INCOSE IS Panel.

[9] TTCP (2003), "Guide to Capability-Based Planning", T. P. Joint Systems and Analysis Group, The Technical Cooperation Program.

[10] Davis, A. (2002), *Analytic Architecture for Capabilities-Based Planning, Mission-System Analysis, and Transformation*, RAND.

[11] http://www.nectise.com

[12] Bahill, A.T. & Gissing, B. (1998), "Re-evaluating systems engineering concepts using systems thinking", *IEEE Transactions on Systems, Man and Cybernetics,* Part C: Applications and Reviews, 28(4), 516-527.

[13] INCOSE (2006), http://www.incose.org/practice/fellowsconsensus.aspx, accessed on 17 Feb 2009

[14] IEEE 1220-1998. "Standard for Application and Management of the Systems Engineering Process", Institute of Electrical and Electronics Engineers, Inc. New York, New York.

[15] Kaplan, J.M. (2006), "A New Conceptual Framework for Net-Centric, Enterprise-Wide, System-of-Systems Engineering", National Defense University Center for Technology and National Security Policy, Fort Lesley J. McNair, Washington DC. CTNSP. http://www.ndu.edu/ctnsp/Defense_Tech_Papers.htm

[16] Goode, H.H. & Marchol, R.E. (1957), *System Engineering: An Introduction to the Design of Large Scale Systems*, McGraw-Hill, New York.

[17] INCOSE (2000), "Systems Engineering Applications Profiles Version 3.0".

[18] Hitchins, D.K. (2007), "What's in a System-of-Systems? ". http://www.hitchins.net/SystemofSystem.pdf

[19] MIT, http://cesf.mit.edu/about.html

[20] Maier, M. W. (1998), "Architecting Principles for Systems-of-Systems", *Systems Engineering*, 1:4, 267-284.

[21] Keating, C.B (2005), "Research foundations for system of systems engineering"; *2005 IEEE International Conference on Systems, Man and Cybernetics*, 3, pp. 2720 – 2725.

[22] Henshaw M.J.D., Dickerson C.E., and Lawrence R. (2008), *SoSE for the management of capability enabled by networks*, presentation in a special session on SoS at ICSOS, Jun08, Monterey, Ca. http://www.ICSoS.org

[23] De Laurentis, D., Dickerson, C., & DiMario, M. (2007), "A Case for an International Consortium on System-of-Systems Engineering", *IEEE Systems Journal* 1(1), 68-73

[24] Maier, M.W. & Rechtin, E. (2000), *The Art of Systems Architecting*, Boca Raton, FL: CRC Press.

[25] News for Systems Engineers (2008), Issue 15

[26] Touchin, M. & Dickerson, C. (2008), "Architecting for Capability" *Proceedings of the Conference RNEC'08*, Leeds, UK.

[27] Eisenhardt, K.M. & Martin, J.A. (2000), "Dynamic capabilities: what are they?" Strategic *Management Journal*, 21, 1105-1121.

[28] Zollo, M. & Winter, S.G. (2002), "Deliberate learning and the evolution of dynamic capabilities", *Organization Science,* 13(3), 339-351.

[29] Zott, C. (2003), "Dynamic capabilities and the emergence of intra-industry differential firm performance: Insights from a simulation study", *Strategic Management Journal*, 24, 97-125.

[30] Wang, E., Klein, G. & Jiang, J. J. (2007) "IT support in manufacturing firms for a knowledge management dynamic capability link to performance", *International Journal of Production Research*, 45 (11), 2419 – 2434

[31] Teece, D.J., Pisano, G. & Shuen, A. (1997), "Dynamic capabilities and strategic management", *Strategic Management Journal* 18 (7), 509-535.

[32] Ngo, L.V. & O'Cass, A. (2009), "Creating value offerings via operant resource-based capabilities" *Industrial Marketing Management*, 38 (1), 45-59.

[33] Bar-Yam, Y. (2003), "When Systems Engineering Fails --- Toward Complex Systems Engineering" *Proceedings International Conference on Systems, Man & Cybernetics*, 2, IEEE Press, pp. 2021- 2028

[34] Norman, D. O. & Kuras, M. L. (2004), "Engineering Complex Systems" Mitre Corporation Technical Report, Case 04-0443, http://www.mitre.org/work/tech_papers/tech_papers_04/norman_engineering/norman_engineering.pdf

[35] Swarz, R.S. & DeRose, J.K. (2006), "A Framework for Enterprise Systems Engineering Processes", Mitre Corporation Technical Report, Case 06-1163. http://www.mitre.org/work/tech_papers/tech_papers_06/06_1163/06_1163.pdf

[36] DE&S UK MoD (2008), "Implementing Systems Engineering in Defence", Unclassified MoD document.

[37] Dörner , D., (1996). *The Logic of Failure*, Basic Books

[38] Curtis, N. J., Dormans, P. J. and Ciuk, J., (2006), "Doing the Right Problem versus Doing the Problem Right: Problem Structuring within a Land Force Environment", *J Opl Res Soc*, 57, 1300-1312.

[39] Jackson, M.C. (2003), Systems Thinking: Creative Holism for Managers, John Wiley & Sons