A structured approach to planning and managing systems engineering capability evolution in a complex through-life business space

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Abstract

This paper presents ongoing work to structure how we transform systems engineering capabilities to address the how to engineer with a focus on operational capabilities rather than just systems. The paper is based on BAE Systems capability development work, informed by engagement with UK MOD as they move towards managing for capability outcomes.

The approach taken has been to construct a concept model and a management process:

- Model – the priorities for the model are clarity and simplicity. The model describes a framework divided into cells in which to describe the systems engineering capabilities necessary to conceive, develop, support and operate systems to realise operational capability.
- Process – the process covers both the early discovery stage, and the predicted longer term phase of capability evolution.

The paper discusses results to-date and potential future work towards a more rigorous description and assessment tool, intended to have wide applicability.

1 Introduction

This paper presents early results from the development and application of an approach to assess, plan, and mature the systems engineering capability necessary to address the breadth and depth of various capability management challenges. This approach is intended to enable industry and customers together to ensure that the right systems engineering capability is deployed to develop and manage elements that when integrated enable customers to realise operational capability. This emerging focus on operational capability is a significant shift from the traditional and predominant focus on engineering individual platforms and systems.

This approach is based on work with the UK Ministry of Defence, and its Through Life Capability Management (TLCM) initiative, although, as this paper discusses, the approach is being developed to address other national and business sector contexts.

A previous paper [Touchin and Dickerson 2008] focused on the need for capability architecting, noting that it is, in essence, a System of Systems Engineering issue. This paper focuses on defining a model and process to enable the definition and assessment of those systems engineering capabilities. Note that this set of systems engineering capabilities may be provided within the joint customer and industry collective. Related papers, focusing more specifically on the integration aspects and the competencies needed, have been given earlier this year at the INCOSE UK Spring Conference and the Conference on Systems Engineering Research 2009 respectively.

After this introduction the paper assesses the Business Challenge (Section 2), the Approach taken (Section 3), describes the creation of the Model (Section 4), and discusses use of the Model and early outputs (Sections 5 and 6). Section 7 summarises the paper and identifies avenues for future work.

1.1 Review of Previous Work and Key Inputs

This paper builds on existing work, and seeks to integrate and enhance rather than to re-invent. Table 1 lists these inputs and identifies the key inputs to this paper.

Table 1 Review of Key Inputs

Reference	**Key Inputs to this Paper**
UK MOD Acquisition Operating Framework (AOF)	The core reference for Through Life Capability Management (TLCM) as expressed by the UK MOD. Defines the Defence Lines of Development (DLOD) which represent the parallel tracks of development that must be integrated to realise Military Capability.
UK MOD Architecture Framework (MODAF)	MODAF is the UK MOD’s chosen implementation of an Enterprise Architecture Framework – a mature example on which to base this work. MODAF includes guidance on usage to understand and manage acquisition across DLOD and integration
ISO/IEC 15288:2002 Systems Engineering Lifecycle Processes	Contains the definitive set of systems engineering lifecycle processes, used in this paper to inform both Lifecycle and the complete set of processes necessary to engineer systems.
UK MOD Systems Engineering Handbook	This Customer view contains a layered view of Systems Engineering for their enterprise divided into: Capability, System of Systems and Project levels.
INCOSE Systems Engineering Handbook	Description of the key process activities performed by systems engineers, consistent with ISO/IEC 15288:2002.
INCOSE UK Systems Engineering Core Competencies Framework	Best practice set of systems engineering competencies. This set predates TLCM, and this paper proposes refinements to address emerging new/differing competency needs.
“Architecting for Capability”	The latest UK MOD/Industry/Academia view of how to apply systems engineering to realise Military Capability. The paper is coherent with and builds on the AOF, and ISO/IEC 15288:2002.
“Implementing Systems Engineering in Defence”	This UK MOD paper emphasises the importance of Systems of Systems Engineering as the basis of realising Military Capability.
“Interoperable Acquisition for Systems of Systems: The Challenges”	This paper characterises the Interoperability challenge which must be met in order to achieve effective Systems of Systems, that are integrated and that can realise operational capability.

1.2 Terminology Used in this Paper

The following key terms are used in this paper

Table 2 Key Definitions

Term	Definition and source of definition
Capability	The ability to achieve a desired effect under specified standards and conditions through combinations of means and ways to perform a set of tasks (US CJCSI 3170.01E, consistent with UK MOD). Can be summarised as “the ability to achieve a specified effect”
Military / Operational Capability	The ability to achieve a specified Military/Operational effect. (Touchin & Dickerson 2008)
Industrial Capability	The ability to provide equipment/ services. (Touchin & Dickerson 2008)
System	A combination of interacting elements organized to achieve one or more stated purposes. (ISO/IEC 15288:2002) Note: A system may be either a product or the services it provides.
System of Systems (SOS)	A set or arrangement of systems that results when independent and useful systems are integrated into a larger system that delivers unique capabilities. (US DoD System of Systems Engineering Guide)
Competency	The ability to perform activities to the standards required in employment using an appropriate mix of knowledge, skill and attitude. (IET).
Through Life Capability Management (TLCM)	The translation of requirements within Defence Policy into an approved programme that delivers the required capabilities Though-Life, across the Defence Lines of Development (DLODs). The terms Through Life Capability Management and Capability Management are interchangeable. (UK MOD)
Wicked Problem	A term adopted from social planning referring to a problem that is difficult or impossible to solve because of incomplete, contradictory, and changing requirements that are often difficult to recognize (Rittel & Webber 1973).

2 The Business Challenge

Organisations managing complex enterprises (e.g. Ministries of Defence, other Government departments, and corporations) are increasingly looking to acquire and manage capability instead of focusing on systems and equipment. This change is due to a number of factors, including: shrinking budgets/value-for-money concerns; and the need to respond to complex and unpredictable operational environments. By focusing on capability, and by taking a through-life perspective, customers can better assess how they can meet their operational needs, and can better understand and balance acquisition and operational/support costs.

This capability focus requires some different engineering approaches, and the aim of the model described in this paper is to identify and realise them in an effective manner. This challenge extends wider than the System Engineering discipline, across all project delivery functions, including integration between functions. Although this change will not affect all associated activities, there will be clear impacts in many areas including the competencies needed, the processes used, and the interactions between customers and suppliers. This is particularly important given that it is recognised that the decision-making necessary to plan and realise integrated capabilities will require greater collaboration than previously.

Given the diversity of elements involved, and the number of different options for capability solutions, capability needs are not well suited to traditional, "hard" systems requirement definitions. Solutions are further constrained by the need to make effective use of extant or legacy systems/elements, thus rendering change complex. Meeting such capability needs is therefore an example of a 'Wicked Problem' [Rittel and Webber 1973], and requires a fully collaborative approach by all stakeholders.

One key issue is that of Interoperability, which affects through-life costs as well as the degree of success in realising capability. The UK MOD recognises the need for "interoperable acquisition", defined by Smith and Phillips [2006] as:

> "The set of practices that enable acquisition, development, and operational organizations to collaborate more effectively to field interoperable systems"

They consider interoperability as having three aspects:

- **Operational interoperability** is closely aligned with the traditional definition of interoperability (the ability of systems to exchange relevant information), but it adds the notion of compatible (or complementary) operational concepts.
- **Constructive interoperability** reflects the degree to which the different system design, engineering, and production processes and tools involved in realising operational capability are able to exchange information in an understandable manner.
- **Programmatic interoperability** expresses the ability of programmes to exchange information about the management of the programmes involved. This information can range from budget and schedule information to details on how to interpret risks.

3 Approach

The challenge we face is significant and the method of approach is crucial in ensuring its success. The approach taken is based around the following three tenets:

- Practicality – basing all work in plain and shared language to ensure good engagement with all stakeholders.
- Convergence – aiming for common competencies and processes to be applied across the extended customer-supplier enterprise. Exploitation of existing good practice is essential to accelerate progress and to prevent "reinventing the wheel".
- Collaboration - in order to achieve our aims within short timescales, we must share knowledge, experience and views with customers, wider industry and academia.

The approach taken is based on an incremental spiral lifecycle with successive spiral iterations addressing the material in a repeated manner, both to "drill down" and also to track evolving thinking in the community.

3.1 Collaboration

Collaboration is one of the fundamental contributors to success; without it our scope will be restricted and our progress limited. Being able to understand the issues and priority areas of our customer, sector and other industries allows us to shape our approach in order to achieve more widespread benefits. Collaboration also allows us to build a common understanding across the community of all parties' areas of interest and priority, identifying external good practice which can be shared with relevant parties.

Collaboration facilitates external capability benchmarking – with the further benefits of identifying appropriate organisations for further collaborative activities, and allowing us to recognise and promote areas of excellence to the wider engineering community.

Within this work we are collaborating with:

- Customers in UK and our other home markets abroad, principally USA
- Industry, both Defence/Aerospace and other sectors via forums such as INCOSE
- Academia, including collaborative research programmes sponsored by our customers.

3.2 Lifecycle

An iterative lifecycle (Figure 1) allows for periodic refresh of objectives, which is necessary given the changing environment of this work. This allows for short term goals to be set which contribute to the longer term aims which can be revisited as thinking matures and priorities change. It also allows for quick wins through rapid deployment of outputs across the business. We have visualised this as a spiral, with four key processes conducted in each circuit. These processes (Understand, Analyse, Decide and Intervene) are discussed below.

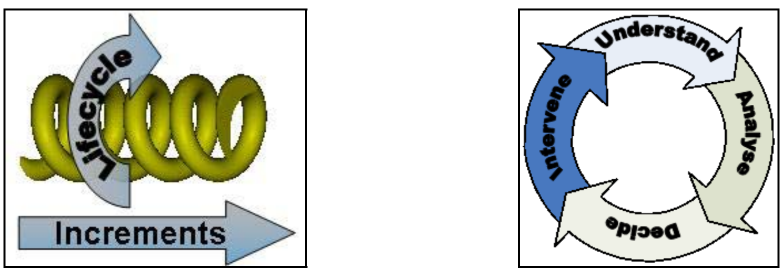

Figure 1 - Spiral Lifecycle

3.2.1 Understand

The first stage of the spiral is to understand the overarching “Big Picture” of the business challenge and to review current abilities to address it. For the first cycle of the spiral, this involves creating a framework to communicate the business challenge encompassing many different viewpoints with a clear language to enable wide involvement.

In subsequent cycles, the role of the “Understand” phase changes; here the target is re-assessed and adjusted to reflect current thinking, timescales and progress to-date. Additionally, this phase allows for success stories to be communicated with the wider engineering population to gain buy-in from key stakeholders and the community at large.

3.2.2 Analyse

The Analysis phase of the lifecycle allows for a comparison between the target and current capability, a view of the gaps between aspiration and current capability.

This phase also allows for a full analysis to be made of other contributing factors to change, including timescales and cost, to allow for a better understanding of the feasibility of reducing or closing the gap in capability, given any actual resource constraints and the expected business gain arising.

3.2.3 Decide

Based on the Analysis of the previous phase, an informed decision can be made on the prioritisation of the gaps and the improvement programmes to be taken forward into the next stage. Metrics must be defined during this phase in order to assess the effectiveness of the improvement programme and whether it meets its intended objectives.

3.2.4 Intervene

Improvement changes only have an effect when they are rolled out and applied. Alignment of improvement programmes with the overarching organisation's strategy helps to gain managerial support and aid in its deployment. The interventions can take the form of either good practice sharing across the business or other industries, or the outputs of a collaborative activity (either internal or with external organisations) on common issues.

During the intervention rollout, it is imperative that the appropriate metrics (as defined in the previous stage) are collected so that an assessment can be made as to the impact of the intervention activity, both for future iterations and for positive feedback to the organisation.

4 Creating the Model

Capability Management can be examined from several different viewpoints, each providing a different perspective of how the operational capability is realised and managed through life. The "Big Picture" for Capability Management can only be realised when all viewpoints are linked up and the mappings fully understood, allowing the observer to examine the resulting "space".

The principal viewpoints considered when building our model are as follows:

- **Customer** – customers' views on capability management, their role in realising operational capability and their expectation of industry's role(s) in this shared space.
- **Lifecycle** – the lifecycle and time aspect of both the operational capability and its constituents; the type and capacity of industrial capabilities necessary is coupled to it.
- **Process** – describes the "how" of industrial capability. We have based this on ISO/IEC 15288:2002 for Systems Engineering processes, while recognising that an integrated set of all disciplines (e.g. engineering, management, commercial, HR, marketing, training) is required.
- **Competency** – industrial capability comprises a number of constituents, with the human element represented as competency and capacity.

We have taken these viewpoints and created a three-dimensional model against which other viewpoints can be mapped. This flexibility allows for future models and thinking to be added into the framework, thus not limiting the model to the "as now" situation. The dimensions of the model are:

- Levels of systems engineering involved in realising operational capability
- Lifecycle / time
- The contributing elements of operational capability (Lines of Development).

The meaning and content of the individual "cells" formed by these three dimensions are described later, including a description of how the other viewpoints can be mapped.

4.1 The Framework

The three dimensions of the model form a cube. Figure 2 shows the front face of the cube which depicts the levels of integration. The bottom layer represents the Systems Engineering approaches (including the lower levels of subsystem engineering) necessary to realise a system across all of its lines of development, including the integration between the elements. The processes and competencies at this level are mature (especially for realisation of physical systems) and form the basis for moving up through the levels.

As the need for individual systems to work together grows in significance, Systems of Systems (SOS) Engineering is becoming more of a focal topic. SOS Engineering requires analysis of how individual systems operate, in order to configure and integrate them to produce effects that cannot be achieved by individual systems alone. This requires a greater understanding of the systems concerned, their interoperation, and how to plan and manage the emergent properties of the SOS. At this level, trades can be made between systems to ensure that the optimal solution in terms of output against budget can be realised.

At the top layer (Capability Management), SOS are brought together so the customer can realise operational capability. At this level there are two key activities: the first is defining the desired operational capabilities and the creation of the underpinning architecture defining the integration of the various elements necessary to realise these capabilities; the second is the management of the operational capability through-life (until the capability is no longer required).

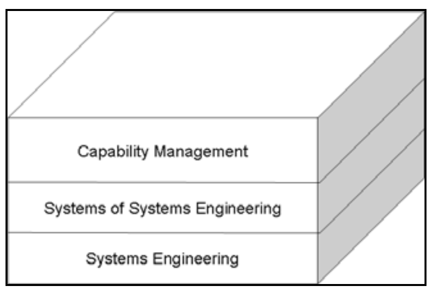

Figure 2 - The Operational Capability Levels

Figure 3 shows the Lifecycle View of the framework. Time and phase have a key effect on the type of systems engineering, and the amount, that is applied. We have adopted the example lifecycle contained in ISO/IEC 15288:2002 “Systems Life Cycle Processes” as the basis. While the focus of the ISO lifecycle is on Equipment & Technology aspects, it is a well-understood point of reference and is coherent with major Government/Industry lifecycles.

Recognising the differing time factors at different levels, there is a need for future work to establish a recognised model of lifecycle/timing at the SOS and Capability Management levels. Whilst the lifecycles for Systems and SOS will generally be different, synchronisation across these different lifecycles is necessary to achieve successful integration – the integrated whole can only be “ready” when all of its elements are.

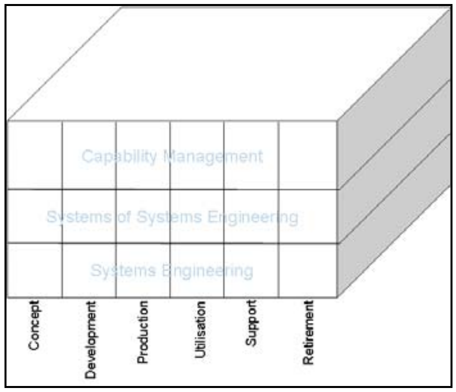

Figure 3 - The Lifecycle View

The framework is extended into the third dimension with the constituent elements that integrate to realise Operational Capability. UK MOD defines these as the Defence Lines of Development. For this paper, we have used a more generic set (see Figure 4):

- People (including Training and Organisational aspects)
- Process (including Doctrine/Policy and Information)
- Equipment & Technology
- Infrastructure
- Sustainment

At the SOS level, Systems are not only integrated within but also across the lines of development ensuring that a consistent approach and understanding is maintained across all elements (for instance, training facilities and organisations being merged, common logistic support arrangements for a composite vehicle fleet). At the Systems and/or Systems of Systems level, trades can be made across these elements to ensure that the optimal balance in terms of through-life cost against achievable effect is realised.

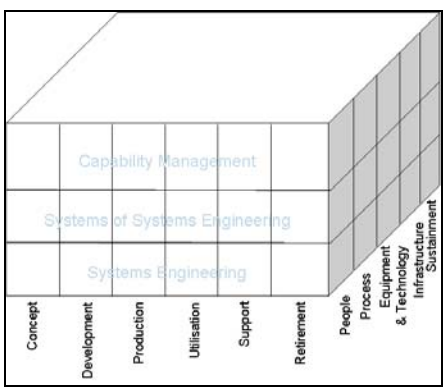

Figure 4 – Operational Capability Elements View

Although the framework has been created from an Engineering viewpoint; this is not purely an Engineering problem. Indeed, the model must embrace all relevant disciplines (e.g. Project Management, Commercial/Procurement) to understand the complete challenge.

4.2 The Individual Cell

The individual "cells" of the model partition the activities necessary to realise and manage the operational capabilities according to the level of integration, lifecycle stage and applicable line of development. Independent of whether these activities are performed by customer, user or industry, the model must contain a description sufficient to enable assessment, gap analysis, and identification/sharing of good practice. In many cases, the boundaries between cells are not well-defined, and there are many complex interrelationships amongst the cells to be considered.

Depending on the intended use of the model, the cell can be used to view the following (discussed in more detail below):

- Processes, and process integration
- Competencies
- Participants
- Current Activities
- Good Practice.

4.2.1 Processes

The basic language of engineering process adopted for this model is that of ISO/IEC 15288:2002, but others could equally well be used

Traditional Defence/Aerospace experience is at the System/Platform Engineering level in the Equipment and Technology line of development. So what does extending our offerings across other lines of development mean? Will all of our current engineers need to be re-trained? The short answer is no; in moving across the lines of development, across the lifecycle and up the levels of integration, the engineering fundamentals do not change but the context in which they are applied does.

The model can be used to capture what engineering processes are required to operate in each cell and, more importantly, to identify the subtle differences in operating amongst the different cells. To understand the required changes, it is important first to understand the cross-functional view of the model, onto which those processes which are cross-domain (e.g. between engineering and management) must be mapped. This allows the observer to understand fully the dependencies between engineering and other functions, and will prompt cross-domain working in order to meet the business challenge.

4.2.2 Competencies

The basic language of competency in this model is the INCOSE UK Systems Engineering Core Competencies Framework.

While it is reasonable to predict that these core competencies apply across much of the framework, there are likely to be specific signature competencies in each cell. Mapping these allows an assessment of current organisational capability and gaps, and to define gap-closure solutions where required. Some examples of early signature competencies identified include:

- Systems Thinking
- Holistic Lifecycle View
- Effective Collaboration Skills.

4.2.3 Participants

Achieving the higher levels of capability management requires collaboration between several parties and management of overlaps and dependencies. This includes customer organisations (e.g. user, purchaser, training), and suppliers at varying levels (e.g. prime, subcontract, small/medium enterprise, consultancy). The ability to map where these organisations currently operate in the model will enable a better understanding of how they should interact, and how they could evolve.

For many complex systems, we work closely with our partners to provide an enhanced offering that can only be achieved through such collaboration. Representing all relevant stakeholder activity in the model enables a full understanding of who is operating where and at what level, helping to identify future partners for collaboration, and is key to adopting a common approach to understand better the customer's needs.

4.2.4 Current Activities

Mapping current activities against the framework enables the observer not only to understand the depth of the offering at each level but also, by scoring each activity, to gauge its maturity. There will be some areas in which business will be stronger than in others; the model helps to identify the weaker areas, where the capability can be improved either through good practice sharing (see below) or through focussed internal funding to tackle the priority areas.

4.2.5 Good Practice

For some areas, an activity will demonstrate good practice either through the optimisation of processes and tools or with a "nugget" of practice which has been developed to overcome a specific problem – a problem that is most likely to be prevalent in other areas of the cube.

In order to achieve capability within a cell all the above views have to be integrated and working as a system; it is not enough to have only the process elements but no people with the right skills and competencies to execute them. The inter-relationships between cells must also be fully understood to avoid disjointed phases and disconnected capability elements.

5 Using the Model to Understand

To facilitate understanding the information held within the model from different viewpoints, the cube allows different slices to be displayed to view different aspects of the data, perhaps to examine a single Line of Development or phase of the lifecycle (see Figure 5).

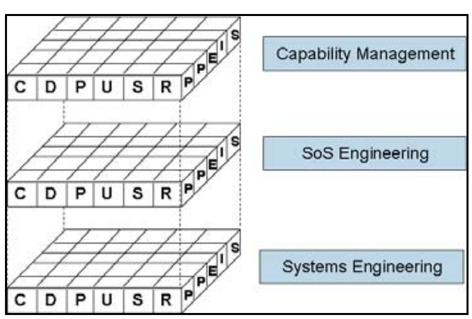

Figure 5 - Slicing the Cube

The model can be used to map business aspirations, in terms of where the organisation would like to operate in the future and also the desired operational capability levels. By aligning the model to company strategy, the model is a useful tool with which to communicate the aspirations cross-function (see Figure 6). The view on where an organisation would like to operate is based both on the current view of where all the stakeholders (customer, the business, supply chain and the competition) are operating, combined with some of the parties' aspirational views, in particular the customer view of the role of industry.

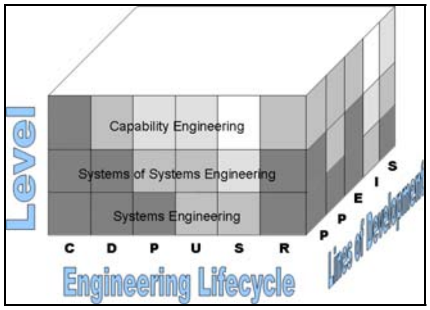

Figure 6 - The Framework - Aspirational View

By undertaking a comprehensive assessment of the current offerings in each area, a view of the current situation can be obtained (see Figure 7) which, when compared with the aspirations, can provide a view of the shortfall in each cell. By quantifying the gap and applying a simple traffic light scheme, the model can be used quickly to identify priority areas and better to inform a change management programme. Comparing two or more cubes allows the observer to identify common priority areas for collaborative focus and also the potential for quick wins and gap fill through good practice sharing.

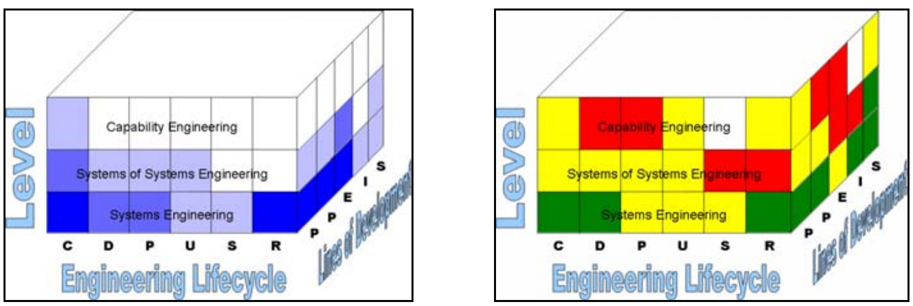

Figure 7 - The Framework - Current View & Gap Analysis

In the long term, by regular update of the "as-is" situation and subsequent gap analysis, a view on progress can be taken and aligned with the expected progress defined in a change management programme. Comparing the actual progress against forecast allows a business to review its strategy; taking into account the timescales and current progress (see Figure 8).

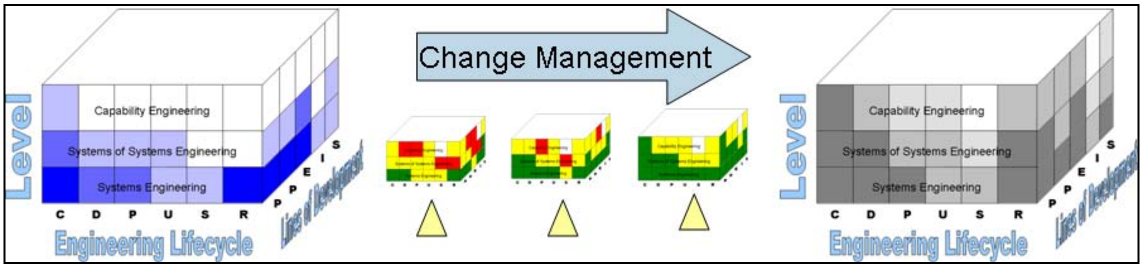

Figure 8 - Using the Framework - Change Management

6 Early Outputs

We have taken a spiral development approach in populating the model. As this model represents a relatively new concept, we envisage that there will need to be several iterations before the model is fully populated. Use of the framework has, however, already produced some useful outputs to be taken forward.

We have recently undertaken a survey across the business in order to understand better where our current programmes map against the framework. This has helped us to appreciate where different businesses are operating, and also provides a better understanding of business priorities and common areas for focus. We have already identified some quick wins through good practice sharing, and it has enabled us to start on the education journey that our engineers will need to take by challenging them to think about how their current practices will work in the domain of TLCM.

Through the communication surrounding the framework, we have been able to improve our connections within the wider community of practice, including those with our customers, and also with existing collaborative organisations such as the Software Systems Engineering Initiative (SSEI). This all allows for better understanding of the overlap between our respective activities and the priorities for common focus. Our framework has also provided a useful mechanism for dialogue with other business functions regarding the capabilities they will require to operate at the higher levels – it will not be a case of business as usual!

7 Summary and Future Work

This paper has described the initial stages of model and process development, and early results achieved. The process shows how we intend to continue the work, and hence to use systems engineering principles to evolve our capability to meet customer needs in the evolving marketplace.

So, how can we take this forward?

- By maturing and sharing the model, we can improve our ability to engage with our customers to understand their positioning, our opportunities, and to prioritise our capability evolution.
- Through using the framework to identify and mature competencies and processes required across all functions we will mature our overall business readiness.
- Further use of the model, ensuring that it is expressed in domain-neutral language, will help us engage with other business sectors to further share good practice.

Our longer term hope is that this framework helps establish the basic language of Systems Engineering for Capability Management. This will provide a basis for the sharing of good practice and the evolution of engineering competencies, as well as the associated learning and development approaches.

The changes that will be required will happen over several years, but, through improved working with our customers, partners, supply chain and other industries, we can support this process and ensure that a common set of goals is achieved.

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Biographies

Alan Harding is a Consultant Systems Engineer in BAE Systems Integrated System Technologies. He has over 20 years of systems experience in defence and security domains, gained while working for BAE Systems, BAeSEMA, Sema Group, and CAP Scientific. His current role is as the Chief Systems Engineer of a major UK Government IT-enabled Change Programme. Alan chairs the BAE Systems UK Platforms & Solutions Systems Engineering working group, and represents the company in the INCOSE CAB and UKAB.

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Malcolm Touchin worked for many years on a range of naval command and control systems, initially with Ferranti Computer Systems where he was involved in the successful introduction into service of the Royal Navy's 'Hunt' Class Mine Countermeasures Vessels, then with CAP Scientific, and more recently for BAE Systems in the Mission Systems team for the Royal Navy's new Aircraft Carrier, leading the earlier stages of the Information System design and the overall system architecture development. He has been at the SEIC since 2006, initially as Technical Manager, but now engaged in many aspects of BAE Systems' research in Through Life Capability Management.

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