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New Process and Structure Thinking for Capability Development

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Abstract

The paper discusses the definition and provision of military capability, and considers two themes. The first theme describes the underpinning Systems Engineering Process Lifecycle required to support the development and procurement of capability, suggesting that current Process lifecycles are inappropriate for capability development and procurement. The second theme illustrates the impact and implications of this new Process. The discussion offers a view of the underpinning system architectures required to support these constructs, based on the hypothesis that an 'architecture' is simply 'an organisation of resources'

Analysis of the engineering / business impact of the new process lifecycle suggests that the development of complex, inter-related systems - procured to support the delivery of capability – requires a structured development environment in which all the constituent components of capability can be assimilated. This structure is defined as 'The 5 Column Model', and various emergent products of the model and its implementation are highlighted.

The paper briefly extends this new Systems Engineering model to a defence-wide view of capability provision, where the basic concepts are retained in a scalable version of the original, and the 'tail' of the model represents a Defence-wide development structure for analysis and experimentation.

Introduction

Modern defence acquisition is today expressed less in terms of items of equipment and more from a 'capability' perspective. This move from the tangible to the abstract gives rise to several issues and conflicts – not least of which is one of definition. In the UK, the Joint Doctrine and Concepts Centre offers a framework (Figure 1) in which 7 'capabilities' are defined as the primary goals of the military domain and they are expressed as verbs; Command, Inform, Prepare, Project, Protect, Sustain and Operate [Ref:1]. This represents a 'Customer' perspective of Capability, and to express these capability needs in terms of a satisfactory implementation whereby solution options may be discussed, requires further analysis and breakdown. Clearly aspects of these activities are hierarchical in nature; they are scenario dependent and may be satisfied by a wide range of solution artefacts such as equipment, people, processes and procedures, policy etc. In general, a number of these terms are not amenable to enumeration and measurement. How much 'Protection' is required will be dependent upon the scenario, the circumstances, inter alia.

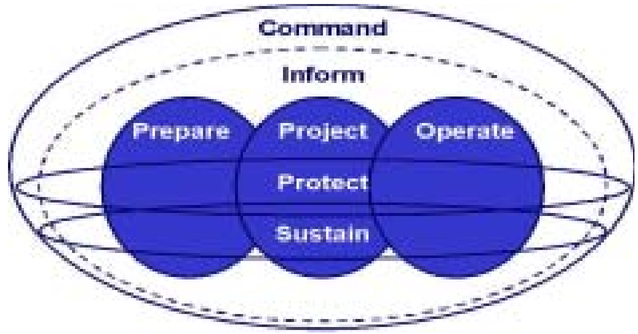

Figure 1: UK Joint Doctrine and Concepts Centre Capability Framework

Industrially the perspective changes and 'capability' tends to be defined in a very different structure (Figure 2), comprising 5 elements of People, Process, Product, Access to Technology and Facilities. These are generally tangible things (rather than abstract concepts) and can be articulated much more easily in numerate terms (how many), in value terms (how much) etc. The relationship of the 5 elements is also more clear cut than those expressed in abstract terms, as each offers some contribution to the development and subsequent sale of product – the product is the focus of the Industrial capability definition. This then represents the 'Supplier (of the product)' perspective of capability.

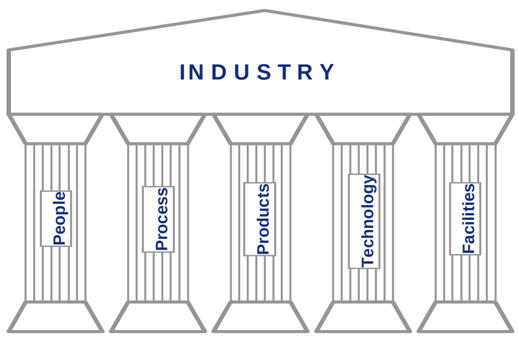

Figure 2: Industrial Definition of Capability

Clearly, without some degree of effort, these perspectives are not compatible (indeed in some circumstances they are in conflict) and a middle ground must be sought if Capability-based acquisition is to be a reality.

An approach to this middle ground can be found today in the UK environment where the concept of the Line of Development (LoD) has been garnering significant interest. Originally structured from military operations, the LoD concept has offered a third interpretation of capability and comprises currently 6 elements – the Equipment, Manning, Training, Sustainment, Tactics and Doctrine, and Force Structure & Infrastructure. From these components capability is 'derived' by having the;

'right equipment, operated to known rules of operation by trained personnel who are sustained in theatre within a recognised and known organisation'.

[NB: It is appreciated that much current thinking [Ref. 2] defines a 7^{th} Line of Development as Industrial Readiness. As this construct has not been recognised formally, it is not included in this analysis, although such a development line adds considerable weight to the proposed hypothesis.]

Each of these 3 capability interpretations is correct for a particular audience and perspective. A primary issue is the reconciliation and combination of these perspectives so that an appropriate customer – supplier – user relationship can be established for the mutual benefit of the contributing parties. If the LoD concept and structure does represent the middle ground, bridging the gap between Customers and Suppliers, then the 'Customer' perspective represents the definition of the need for capability, whilst the Supplier perspective represents primarily the satisfaction of the equipment LoD, with secondary contributions to the Training and Sustainment areas. Other bodies have primary responsibility for the non-equipment areas that are fundamental to the provision and delivery of capability. In essence these authorities act independently with little influence or control over each other. If capability delivery is to be achieved from the design of a system solution that 'integrates' the 6 Lines of Development, then this requires a comprehensive overarching view of the system to ensure that the emergent properties and system trades are managed.

The operational environment in which these perspectives must be reconciled is also undergoing some important changes. Today the concepts of Network Enabled Capability or Network Centric Warfare are central to the defence domain and the 7 UK Capability verbs must apply within such an operational environment. Thus the ideas and issues of Network Enabled Command or Sustainment or Projection must be considered within the design solution and concept thinking.

But the operational environment is an extremely fluid, dynamic environment where the optimum combination of resources necessary to conduct operations may change radically and rapidly between operations. However it is not possible (either practically or because of resource limitations) to change the resources between each operation to enable the optimum outcome. Often the second and subsequent operations are conducted using the equipment of the first on an 'make do' / 'do the best' style rather than through more considered approaches. Thus the delivery of capability must be considered much more formally than in the past across multiple scenarios, through well-balanced (rather than optimised) resource allocation, with flexibility and adaptability high in the requirement pecking order.

If the environment is defined by multiple (potentially conflicting) definitions of capability, characterised by a structure of network connectivity and a need for detailed system balancing and re-balancing, how can the players bring the whole together and achieve successfully the end goals and effects?

One mechanism by which these different perspectives may be drawn together is through consideration of the architecture of the system that would be required to enable and support the different viewpoints. The development of 'architecture' as this reconciling agent has however brought its own problems. It seems to some that the word 'architecture', the verb 'to architect' and the general nuance of 'architecting' has recently been elevated to a status hitherto unheard of in the realms of systems engineering, systems design and system development. It seems that the latest buzzword and activity revolves around architecture. This is not to say that it is not important but the almost cult status afforded architects seems to be misplaced at best, and missing the point at worst.

What is an Architecture?

Definitions of architecture and architecting abound. A current personal favourite from the literature was presented by the AIAA in March 2003 [Ref 3], where;

'Architecting is the art and science of designing and building systems using solution-based, method-based, stakeholder-based and lessons learned methodologies preserving end users needs for performance within suppliers capability to perform.' AIAA Monthly Magazine March 03

This comprehensive definition captures successfully all the differing perspectives of an architecture and its definition. But it may also be too complex to be truly useful and hence may obscure and hinder a more fundamental understanding. Its very comprehensiveness may in fact diminish its usefulness.

In other documentation, the DoDAF [Ref. 4] defines an architecture as;

'the structure of components, their relationships, and the principles and guidelines governing their design and evolution over time' DOD Architecture Framework V2.1 Apr 2000

This shorter description considers the elements of the architecture, how they might relate to each other and (as a framework document) suggests various rules by which an architecture must abide both in the present timespan and possible future development. This seems to be a much more tangible and meaningful description but it is still contains 8 distinct concepts within its phraseology - structure, components, relationships, principle, guidelines, design, evolution and time. The terminology of 'structure', 'components', 'relationships' etc. give an impression of rigidity - whereas the essence of future architectures (within a Capability based, NEC structured environment) will be flexibility, adaptability, combination and re-combination.

Using the current concepts of architecture therefore with their 8 distinct perspectives to describe and reconcile capability perspectives that have their own set of attributes seems to be piling complication upon complication. The definition of architecture offered within this paper is simply that an architecture is;

'an organisation of resources'.

Architects (in the building domain) have been organising resources ever since Man began constructing buildings - from simple houses to cathedrals (Figure 3). Each of these examples visibly illustrates an 'organisation of resources' - the bricks and mortar - but implicitly also contains underlying architectures in their construction - the organisation of the designers, of the builders themselves, the materials, the tactics and doctrine, the logistics and support; each of these are resources to be organised to achieve the effect, each is an architecture to be considered.

Figure 3: Examples of C3I 'Organisations of Resource'
(The authors personal photographs)

So, with the simple language construct as the premise, what are we asking of an architecture in today's capability based world and in particular in today's military environment?

The Function & Attributes of an Architecture

What is the function of an architecture - what drives us to 'organise our resources'? Clearly in the examples given, the individual constituent mounds of bricks, sand and water are somewhat less impressive than the structures that result from their organisation. The individual assets are not likely to provide any measure of the Command, Control, Communication and Information that the resulting buildings achieved in the context and time of their construction. Thus, one aim of an architecture is to achieve something collectively that the individual assets cannot deliver by themselves - some emergent property or the support of some required function and activity. This could be argued to be the process of integration.

Another aspect of the function of an architecture is to enhance what individual assets can do by achieving some element of efficiency through the organisation. Industry and Military organisations are forever 're-structuring' their resources to deliver improved performance, or to reduce costs etc. This re-organisation of resources - the establishment of new architectures of business - therefore seeks efficiencies in the use of resources, improvements in the speed of delivery of output or the transmission of information, consistency of interpretation of a business context / command intent etc. Thus an architecture is perceived as necessary to achieve performance, to enable timeliness and efficiency of resource usage.

A third set of factors or perceptions that suggest specific organisations of resource are the legal, safety and security constraints in which the assets live and work. The fulfillment of and compliance with rules and regulations often demands or predicates a particular sequence of processes and activities and particular organisations of resource to achieve the required / demanded outputs and results. Therefore architectures may be mandated in some circumstances to enable other activities to be accomplished or accredited, irrespective of (and sometimes in contradiction to) the performance issues, the efficiencies of use etc.

The drivers for architecture definition are found therefore in both the internal and external environments of their use. An oft used acronym for these drivers is STEEPV (Sociological, Technological, Economic, Environmental, Political and Values – Ref: 5) and clearly these issues can have major impact upon the ways in which resources are organised, particularly over time. A flexibility of the organisation is essential to maintain overall effectiveness and performance.

Architectures are, therefore, an inherent part of our world and the ways in which we view the world. Some are established in mandatory fashion to provide a common understanding and common quality of output (rules, regulations and standards); others are established for integration and performance reasons; others still for efficiency reasons; and probably a fourth set for purely convenience reasons - because the assets are there.

But, the world is joining up. Fuelled by digital technology, expectations amongst all areas of society are rising in all areas of technical activity and the same applies to the military element of society. Today's military assets and components of an architecture are not generally single function items (like sand and water). In many areas of operation, there are significant numbers of different assets that might be organised to achieve the same purpose or effect. Thus a function of the architect - i.e. the organiser of the resources - must also be to play tunes between the assets to achieve the appropriate effect and balance in the output. However the characteristics of the balance achieved must encompass the legal issues, the timeliness and efficiency issues, the performance and integration issues, etc. In the modern rapidly, changing military world this balancing act must also reflect the ability to re-organise the assets available and achieve different effects quickly and equally efficiently.

Thus one additional component to be considered in the modern world where there are both multi-functional assets and numerous equivalent assets is the flexibility and adaptability of the architecture to organise and re-organise as appropriate to the need.

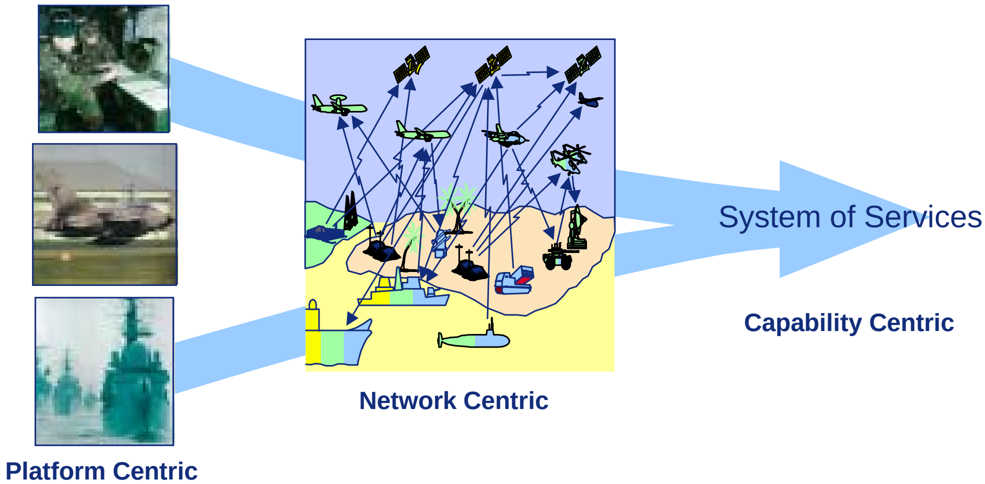

Figure 4: Architecture Transition from Platform to Network to Service Centric in support of Flexible and Adaptable Operations

There is therefore an ongoing migration of the war-fighting systems from the established and familiar platform centric view to the growing Network Centric View (illustrated in the middle of the figure 4), with a further extension of this evolution to a System of Services approach. Recognising that an architecture is merely an organisation of resources, and that the underlying system architectures of this integrated 'joined up world' will need to be open and flexible in configuration enables this. This will enable these resource organisations to be formed and reformed as operational needs dictate ensuring flexibility and adaptability of response through service provision and therefore enable a System of Services approach to deliver the required capabilities. This is not simply a 'bottom-up' view of joining products together; indeed the operational benefit of this architectural transition and network initiative will only be achieved through the ability to include new nodes within the architecture through mechanisms that are robust, measured and simple.

However, even within this interpretation and analysis, it is clear that certain things are not changing. The functionality required of the systems - the 'what is to be done' by our systems - remains essentially the same, and can be expressed in the functional triad of 'Sense Manage Effect'. The major change comes in the 'how well do you need to do it' - the performance, competence (i.e. training and doctrine) and capability issues, all of which are becoming more challenging. Further, it is not just the hard technical parameters of the requirement, but also the 'softer' less tangible and more subjective constraints of the operational context that are demanding new ways of working and system thinking.

The architectures that are put in place therefore must be capable of supporting the achievement of military capability from all perspectives. They will require attributes of;

- performance, capacity and timeliness to enable the delivery of the right resources at the right place at the right time with the right presentation
- resilience and robustness in the face of threat
- reliability and dependability to ensure confidence and usefulness

These attributes are the attributes of any system requirement. They can be applied to the characteristics, functional and non-functional, of any complex system and their definition and evaluation is a crucial element throughout the systems engineering processes of Requirements Engineering, Systems Analysis and Systems Design. The trade-offs between these attributes and the physical components that deliver them form an important part of the overall system trade-off activity. The architecture definition - the ways in which these system resources are organised and the required attributes allocated - is fundamental to that activity.

The Scope of an Architecture for Capability

Today, it is recognised that 5 domains - Land, Air, Sea, Space and Information - define the overall view of war-fighting. Coherence and consistency across these domains of warfare is essential to enhance the contribution of one domain set of assets to the achievement of effect within that, or a separate domain. The organisation of these disparate domain resources will be fundamental to the achievement of Network Enabled Operations and ultimately the desired military effects.

Generally, it is anticipated and appreciated that the future military environment will be dominated by operations involving joint service activities and by coalition forces. These operations will place emphasis upon integration and interoperability of equipments and systems, of process, tactics and doctrine in order to achieve the desired military objectives and capabilities. Some of the underlying functionality will require, as examples, Common Operational Pictures, consistent communications and coherent understanding of information.

In addressing the overall set of resources available within an architecture, the human participants cannot be ignored. Indeed, the human element of resource organisation and integration may be considered more difficult than the technical, and is determined and constrained by culture, both personal and national. In addressing and balancing the overall organisation of resources therefore, means must be found of resolving or mitigating cultural differences and understanding.

If therefore concepts of architecture are the key to delivering capability, what resources are available to be organised? The obvious resource set for capability is provided through the Lines of Development and in this concept, these Lines are now not a definition of capability but an implementation and delivery mechanism. The resources inherent within the Lines reflect all aspects of operations and hence provide the ‘raw materials’ from which the necessary architectures must be derived.

In UK Capability terms these demands can be expressed in terms of;

- The equipment available must be capable of working together in an integrated fashion where the individual performance characteristics meld together to provide the overall team ability
- Manning and Training - this development function must engender the appropriate confidence and philosophy to support flexibility of action, distribution of intent
- Sustainability - this attribute is achieved through support resources having the equivalent flexibility / mobility of action and ability to support constant play wherever it arises
- Tactics and Doctrine – to provide flexibility of operation and use of equipment, within self imposed Rules of Engagement; the situation rarely affords the opportunity to ‘stop the war’ and swap out artefacts as defence turns to attack or vice versa, the team must 'make do' with the available equipment. The adopted organisation of resource must also be able to counter the surprise attack (asymmetric warfare)

The analysis and development of the necessary organisation of resources - the architectures - which provide this remit, suggest that the essential flexibility and adaptability, further support the move from platform centric through network centric to service centric styles of organisation and activity.

However the provision and measurement of flexibility within an architecture remain major challenges as they are required only to manage change – if there is no change in the environment, there is no reason to be flexible, an optimal static solution will be sufficient. Thus the techniques and processes used to develop the modern war-fighting architectures and solutions must reflect the dynamic nature of the problem as well as providing sound solutions to the (easier) static situation.

Are the Current Systems Engineering Processes Adequate?

The traditional Industry process for Systems Engineering and the development of a comprehensive product portfolio, within its definition of 'capability', is the 'V' model as illustrated in Fig 5 with particular emphasis upon the left hand side of the 'V'. This has served well in various implementations for some time – particularly through the formal processes of Requirements Engineering, System Analysis and Systems Design.

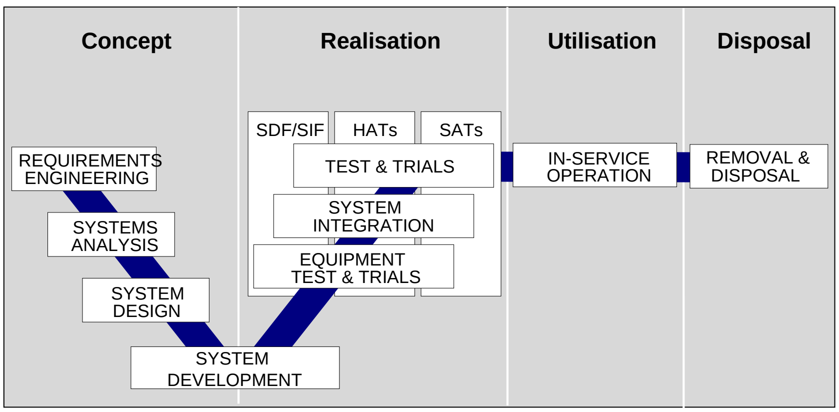

Figure 5: Traditional 'V' Diagram Systems Engineering Process Lifecycle

The right hand side of the 'V' offers Test Acceptance and Integration - each of which enables validation and verification of the design and product. But it is product based. How do the complex inter-system reactions take place and get valued within this structure? It is postulated that this type of 'sequential' process is inadequate and ill posed for the much broader canvas that is required when considering capability.

Figure 6 presents an alternative Systems Engineering Process Lifecycle [Ref. 6]. This model has been referred to as the Reaction Chamber and offers a much more parallel execution of the early stages of requirements engineering and system design than the V model suggests / permits. Here is a formal recognition that certain aspects of those activities must occur in parallel. Additionally it places Systems Analysis processes in a much more dominant and important role – the continuous, through life tail of the process lifecycle. This tail now enables a more defined and coherent through life management policy to be adopted as each of the systems analysis activities offers the opportunity for a measurable system delivery.

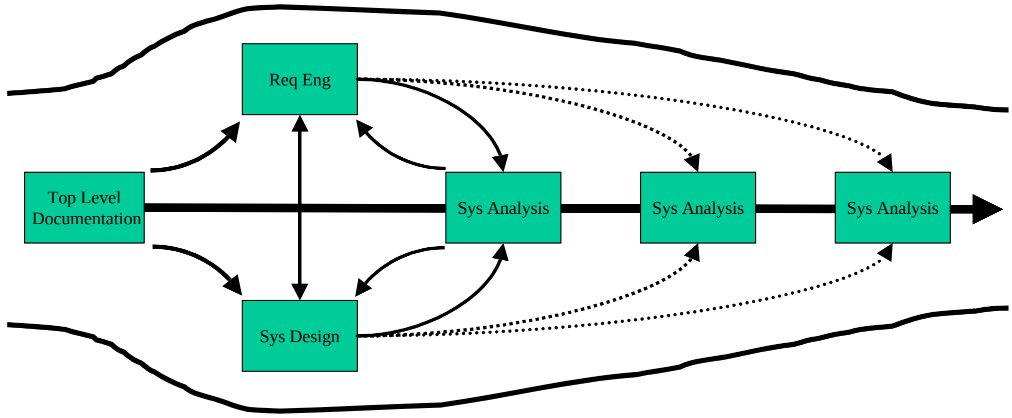

Figure 6: Reaction Chamber Systems Engineering process Lifecycle
(Adapted from Price and John [Ref. 6])

This 'new' model recognises and supports several features essential to both the UK Smart Acquisition initiative and the identification of the appropriate structures for the delivery of military capability. The left-hand side of the diagram represents the standard accepted input feeds of the high-level customer documentation. This includes the Concepts of Operations, of Employment, the Use Cases and the high level requirements – in UK terms the Key User Requirements. As in the traditional and purist 'V' diagram, these initiate the process of Requirements Engineering (in the upper half of the diagram); but now also stimulate formally the operations of in the early design and conceptual phases before products are fully defined and specified (the lower portion of the diagram). Thus the high level documentation acts as a spur to both the Requirements and the Design activities and these two areas have a formal link between them such that each is continually aware of the developments of the other. A much more integrated and communicative approach is therefore engendered.

This is not to suggest however that the requirement is limited or mitigated to merely the art of the possible or achievable. Rather the requirement remains a true statement of the need, and the design activity influences its achievement (to whatever level) cognisant of the many potentially conflicting constraints placed upon it. The outputs of these activities then flow into the Systems Analysis 'box' – the beginning of the tail. In the 'V' diagram, engineers strive mightily to minimise the variance between the requirement and the design solution, to achieve a 100% compliant design solution to the problem. In this new model, the System Analysis box is not used to support that continuous and essentially unrewarding activity. The model explicitly recognises that the design – except in rare or near trivial cases – will not achieve 100% satisfaction of the need. This detailed system evaluation activity now engenders open debate and discussion about the variances, about the importance and value of the key drivers that spawn the differences and about the processes by which the variance might be minimised through life. The System Analysis activity is extended across all components, stakeholders and perspectives of the system and required capability – not just those traditionally defined by the technical equipment performance attributes. This broader scope of evaluation and debate is key to the achievement of viable trade-off processes and activity, to the open management of expectation and the general programme management of risk, schedule etc.

The feedback loops between the various process components are retained but by considering the diagram explicitly as two process sets (represented in the upper and lower halves of the diagram) a number of new perspectives can be included. In the upper half, the traditional understanding and maintenance of the customer / user need is established. The management of the requirement is continued, assessed and compared to the achieved 'performance' (in the broadest scale) of the products defined in the lower half. The continued development of the product – in the real world – brings together the outputs from Research, the benefits of technology development and maturity and the opportunities for incremental acquisition of 'performance' over time. The system design activity continues and each System Analysis component offers the opportunity for a delivery of capability to the customer. This model also suggests that throughout the tail, opportunities exist to refine, develop and match the requirement in a practical fashion via true evaluation of the system. The opportunity also exists for earlier delivery of capability (the programme is not constantly chasing the 100% compliant response) with known 'performance' and military contribution and an identified route through life to improved 'performance' and flexibility in the face of change.

It is also possible to map the capability definitions noted above to this model (Figure 7). The conceptual definitions offered by the 7 verbs of Command, Inform, Prepare, Project, Protect, Sustain and Operate form the requirement and sit in the upper half of the model – this is the 'what is required'. The Industrial definition sits in the lower half – the 'how' it will be delivered.

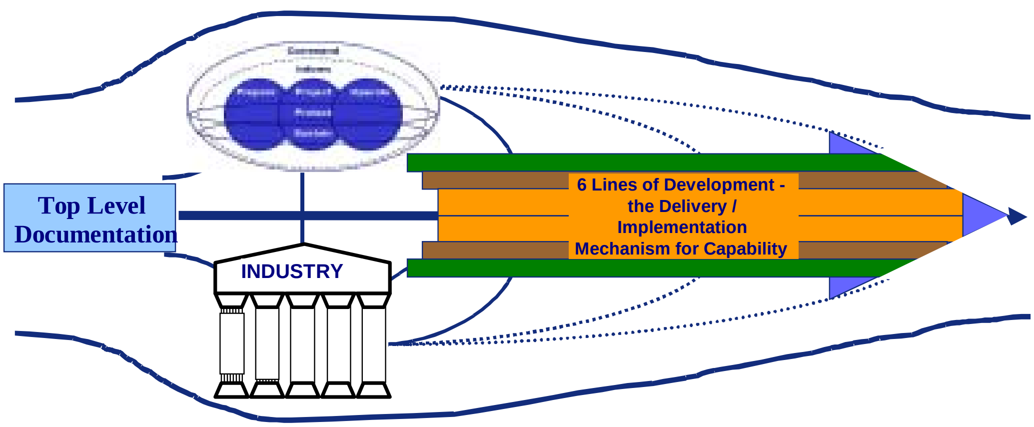

Figure 7: Capability Mapping to Reaction Chamber Process Lifecycle

The Lines of Development – as implementation and delivery mechanisms – then represent the tail of the model reflecting the overall system analysis activities. It is through the interactions and interplays of all these 'development lines' that the capability is delivered, the iteration and balancing of the system is achieved and the overall management of the capability is effected.

Although the lower half of the diagram is represented here as Industry and Industrial Capability, it must also recognise the contributions and activities of the other stakeholders that contribute to the Lines of Development. Thus the 'house' illustrated here is multi-faceted, not just through the elements of industry that design and deliver the equipment elements, but also those stakeholders and (potentially) ministry players that provide the policy, structure and constraints within the Lines of Development in which Industry has much less of an input, such as Tactics & Doctrine, Force Structure and Infrastructure, and Manning. Thus the overall integration of the design problem as expressed in implementation terms through the Lines of Development can only be achieved through a comprehensive partnering arrangement that brings all parties together in a supportive and beneficial way. The issues associated with the delivery of capability through these types of structure are not just technical – commercial and financial issues are just as important to the ultimate success.

A number of emergent products can be derived from this model and the associated capability mapping, the most important of which is the concept of an integrated Through Life Management

Plan that encompasses all facets of the programme and can be applied to both the overall capability required and the component elements that provide the capability. This plan is based upon the ability to evaluate the system (measurement from the lower half) and compare that 'performance' to the need (as expressed in the upper half). As the physical solution concepts and options are planned through life with understanding of the developments of research, technology improvement etc. a plan can be developed that indicates the increment in 'performance' that may be expected within a particular timeframe and cost profile. Thus the capability or system component can be managed against a suite of established management attributes (Price, Programme, Performance) and set against the established customer need.

Such a mapping also enables a much more coherent ability to address the management of change – customer needs both increase and decrease – and the ability to accommodate and manage the effects of change is vital in circumstances of limited procurement / acquisition budgets, timescales etc.

To achieve this mapping and implementation requires considerable change and maturity in a broad range of customer – supplier – user relationships. The 'tail' of the model requires a partnering approach of openness and honesty to achieve the benefits. No one organisation is responsible for all the elements within the Lines of Development and hence the interactions and balancing necessary to achieve a viable (cost effective for example) capability can only be achieved through all stakeholders and parties working together. This overall and combined evaluation of the system encompasses not only the hard performance attributes of speed weight size etc. but also the less objective, more statistical issues of safety, security et al. and these evaluations must be effected across all the components of the system as represented by the Lines of Development. In equipment terms, aspects of this evaluation are present in the concept of readiness levels – this idea must now be extended to include the other Development components such as Manning, Training, Tactics & Doctrine etc. The evolving Systems Engineering processes must establish readiness and maturity definitions for a programme that support rigorous evaluation and comparison between concept options, enable true value measurements to be made from the customer perspective and establish realistic business schedules and responsibilities.

Support for Capability-based System Evaluation

The discussion above places significant emphasis upon the Systems Analysis / System Evaluation component of the engineering. The evaluation requirements are extensive, need to be inclusive of a wide range of parameters and system attributes, and are not confined to the traditional equipment based measures alone. The ability to evaluate and measure the constraints that are placed upon the designer in terms of safety, security and legislative requirements exacerbate the design problem and extenuate the difficulty of providing the appropriate performance elements that can be integrated to provide the required capability. The difficulty in 'thinking through' the transition from Platform-centric views through Network centric to Service centric is matched only by the difficulty in organising, in an optimum balanced fashion, the vast range of assets available.

The 'traditional' systems engineering techniques and 'V' diagram structures for the management of complexity require to be rethought if competent solutions to these problems are to be achieved and implemented. The 'Spiral Development' model is a currently proposed mechanism for the development of capability at its highest level, although it too suffers from similar deficiencies as the 'V' model. In all cases, but particularly within the spiral concepts, the ability to measure and evaluate the system across a broad range of parameters and perspectives is essential. The development of multiple system representations within an environment that enables the integration and evaluation of those representations, may enable such complexity management to be achieved. The underpinning concepts of requirements and functional activities have been discussed above. If to these are added the effectiveness / capability perspectives where potential solution systems are 'tested' in context, then the opportunity exists to develop an embracing development environment for the optimisation of resources and the delivery of complex systems. The ‘5 Column Model’ represents this proposal (Figure 8).

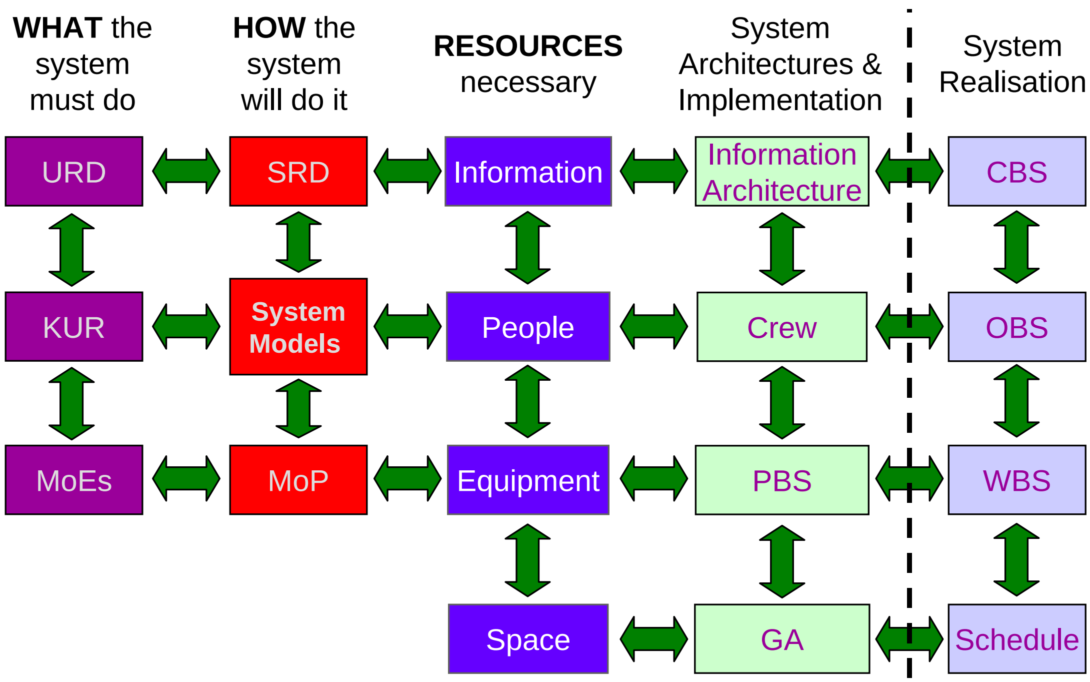

Figure 8: The 5 Column Model, illustrating the components of an over-arching development environment for system design

[NB: This is a schematic representation of the links, offered for simplicity rather than exact detail. The important element of the diagram is the overall connectivity, rather than any individual ‘row based’ connectivity.]

Each of the columns represents a distinct view of the system to be addressed. Reading from left to right;

- 'What the system must do' expresses the key user requirements and capability needs as expressed in the top level documentation
- 'How the system will do it' contains multiple system representations where a range of techniques, such as functional modelling and business process modelling, address individual component performance, maturity and readiness issues
- the 'Resources Necessary' details those artefacts of the real world that are required to populate the execution elements of the system (the functions)
- whilst the System Architectures and Implementation indicate how the required real world resources will be organised to achieve the required functionality and performance and thence the capabilities.

Each of the boxes in this model must be connected. The relationship of one element to those on its left, right, above and below illustrates a different perspective of the whole system. In the full population of this representation, the opportunity exists to ask 'what if' questions at any point, of any point within the system and derive a consistent coherent response for all stakeholders. Thus the model expressed here represents the overall System Synthetic Environment where the opportunities to interrogate the requirement, the design, the implementation etc. are brought together.

The 2nd column provides a fundamental source of system description via the ‘System Models’ box. This area of the environment contains a wide range of system representations to enable an inclusive view for all stakeholders. A key component of this area is the functional model of the system, recognising that the *functions* of war-fighting as expressed by the highest definitions of capability and military effect are unchanging; this system model represents the detail of what has to be accomplished. It is solution independent and hence makes no assumptions about the groupings or organisation of functions, of people, or other components of the world. In the application of this type of model to capability needs, the functions must be enumerated, i.e. they must have a series of numerate attributes (performance, capacity, timeliness et al) and these attributes need to be allocated throughout the functionality in such a way as to ensure the required capability need is achieved when the functions are aggregated together. It is this type of model that places user requirements - particularly the Key User Requirements - in the context of the whole set of activities the ultimate system solution must execute. In design terms therefore, a comprehensive Logical Model acts as a single source of requirement and design information.

Having established the set of required functions and their associated attributes, constraints of the real world can be applied - this is the beginning of the definition of the system architecture. The decomposition of the functional view offers the designer, the system procurer and the system user several key inputs to the achievement of capability. The 'organisation' of the functions initiates debate about the overall system architecture - at which point a range of activities can be brought together to establish system balance and understanding. From a design perspective, the groupings of various functions together enables a detailed engineering view of manufacture and produceability. The interfaces defined by the functional groupings can be considered from a 'who does what perspective'; i.e. they offer opportunities to establish the human-machine interface (HMI) and its information exchange demands and identifies those aspects of system operation that are expected of the user (if any). Finally, the user can begin to understand more fully his position within the system and the demands to be placed upon him as an operator, maintainer etc. Thus the organisation of resources enables an inclusive view of the overall need and of the potential solution opportunities.

A 'Sense Manage Effect' model enables the separate items of the functional chain to be addressed as a whole thread through the system, as well as being considered in individual terms. The thread concept allows for the definition and balancing of a budget - generally of time, but also for the achievement of timeliness - through the system and allows the designer / developer of the various systems to allocate and balance individual system component performance to achieve the required budget. The establishment of a consistent and balanced view of this thread also enables the identification for improvement opportunities, either through technology insertion or through improvements in the underpinning performance of the relevant activities. The clear definition of this thread also identifies the 'hot spots' of the system (on an end-to-end basis), thus supporting focused investment and development. The management of change in the capability required of the system can also be addressed by assessment of the key contributors to the thread.

It is at this point in the design environment that the constraints of the user / operator / domain can be investigated, from numerous perspectives including from an operational doctrine point of view and also through recognising the physical constraints placed upon the architecture by the domain itself. The combination of these perspectives and stakeholders in the development of the initial system architectures plays an important part in the overall development of the system. By recognising and acknowledging these constraints, the opportunity exists to define a balanced architecture (functional organisation) that reflects the needs of the customer, places the user (and the user system interface) at the appropriate boundary within the system, and is visible and understood by the supplier.

Clearly the investigation and generation of system balance can be considered at all levels. For the purposes of example, consider the 4^{th} column - that of System Architectures and Implementation. This column represents the organisation of the fundamental system components;

- the information required,
- the people required,
- the products offered as putative solutions,
- and the environment in which they will operate (the physical General Arrangement of the solution).

These components represent stakeholders in the solution space and in UK capability terms form part of the 6 Lines of Development that comprise the capability delivery mechanisms. The requirements and associated need are expressed, the functional characteristics addressed and a potential set of resources necessary to implement them identified. How then are they to be organised in the most effective way? The 4^{th} column seeks to address that issue. Addressing the issues vertically offers the opportunity to balance automation against people, products against space in the environment (with all the attendant safety issues) etc. Addressing the organisation horizontally, the system balance can consider the mappings of products to functions to cost, of people to training to performance, of information needs to usage and so on.

Within these connections and balances lies the need for performance. The 2 left-hand columns will contain all the non-functional performance parameters of the system (the performance, capacity, timeliness, periodicity, reliance and reliability). As the high-level capability needs are decomposed and placed in context, individual measures of effectiveness and thence solution artefact (equipment) performance can be derived. Analysis of a current example of a C4I product - the Single Integrated Air Picture (SIAP) - suggests that attributes such as

- Completeness The percentage of real tracks that are included in the SIAP.
- Correctness Data accurately reflects true track attributes (position, kinematics, and identity).
- Commonality Track attributes of shared data are the same for each SIAP user.
- Continuity Proper maintenance of track attributes over time.
- Timeliness Data is where it is needed, when it is needed.

are appropriate metrics to be addressed in the development of appropriate organisations of resource. The provision of such attributes will require considerable investment in the management of data and information within a military environment using processes, techniques and applications that are currently prevalent in the commercial environment. Clearly also, the definition of metrics such as these also offers opportunities to organise the collection assets and to recognise their inherent performance attributes within the overall balance of the system.

The integration perspectives of the 4^{th} column therefore seek to establish solutions that comply with those requirements and a process of comparing different resource organisations can be undertaken to ensure optimisation. In this case it is not just a question of people vs. product, but also of comparing information structure A with its associated demands on people and products (and training and population and maintenance), with information structure B and its associated (but different) demands. Hence, the model promotes an inclusive view of system development and highlights the opportunities for all stakeholders to become aware and informed of their place within the system.

Furthermore, such a view also enables and initiates a structured view of through life planning for not only the components of the system but also the capability required to meet the changing demands of the military environment, whether that change is initiated by a change, inter alia, in threat, demography, political intent.

The 5th column of this model actually represents the activities of a Prime Contractor in that his management view of the system is reflected in the Cost, Organisational, Work and Schedule breakdowns of delivery of the programme.

The 5 Column Model operates well within the current UK Smart Acquisition initiative in that it enables a measured response and understanding to the problems of through life management not only of equipment but also of capability. With its intimate support of Systems Engineering process development, the outputs from this model in terms of performance measures, capability statements etc. enable a through life view to be taken of the changing requirements in terms of the threat, the constraints of operations, of support and manning etc. Most importantly, each of these components can be measured and the overall integration of a system, through its many associated 'organisations of resource' can be achieved. The achievement of measurement enables debate upon value and priority and hence provides a framework in which informed trade-off activities and debates can be sponsored.

Any value and priority debate however must be inclusive of system stakeholders including procurers, suppliers, users, maintainers etc. Such debate must be undertaken in the framework of an informed partnership supporting appropriate understanding. The flexibility, adaptability and versatility demanded of our assets within the current war-fighting environments requires coherent and consistent application of development processes and implementation to ensure the correct overall system balance in capability and performance terms.

Extensions to NEC style Environments

An extension to the Reaction Chamber model is represented in Figure 9, which enables a defence wide view of acquisition and procurement to be achieved.

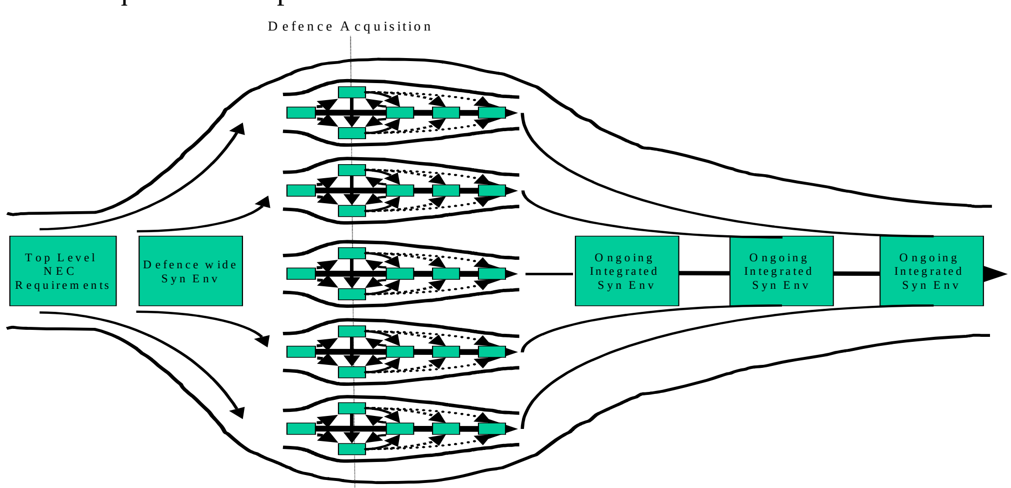

Figure 9: Systems of Systems Style Engineering Process Lifecycle (High Bypass Ratio Model)

The interactions of systems and individual procurements can be addressed for the delivery of across defence, NEC-style effects and capabilities. Now individual capabilities procurements are defined by their own reaction chamber on the axis of the model and the tail is a more global defence wide integration and system analysis / evaluation activity.

The overlaying of the capability definitions on this model clearly identify the need for comprehensive partnering and openness in order to achieve the desired integration and interoperability of equipments, systems and other components that deliver the required defence capabilities. The programme synthetic environment suggested by the 5 Column Model requires a consistency of context and structure that ensures credibility and viability of the proposed solutions and components. The current UK programme NITEworks has established that elements of the customer – supplier – user communities can develop the necessary working arrangements and move the provision of military capability forward across a broad range of activity.

Conclusions

The provision of military capability requires a coherent and consistent environment in which all stakeholders can participate and contribute. The current set of capability definitions gives rise to conflicting views and understanding. A potential key for the provision of capability in an integrated fashion may lie with the development of consistent system architectures, but here the (over)-use and definition of architecture and architecting has distracted from the elementary underpinnings of the activity. Architecture is an 'organisation of resource' which Man has been capable of achieving for a significant period of time.

An increasingly observed characteristic of modern warfare - conducted now in 5 domains - is a primary need for flexibility and adaptability. The ways in which resources are organised to achieve these attributes will require significant change to the ways in which complex systems are perceived, developed and utilised. It is suggested that the overall operational paradigm has shifted from Platform Centric to Network Centric and will move again to a Capability based Service Centric view.

In establishing a set of constructs that would enable this coherency of capability definition and delivery, it is postulated that the current set of Systems Engineering processes and process lifecycle is not adequate for the task, and that the traditional ‘V’ diagram is unable to express the needs of capability provision and development. The ‘V’ representation remains perfectly valid for equipment and product definition, but a new broader process definition is essential for capability provision. The Reaction Chamber model is suggested as a means of providing this broader view. The model can be mapped to the current diverse capability definitions and indicates that the UK concept of Lines of Development offer a sound basis for a partnering approach to the tail of the process which is underpinned by extensive and comprehensive system measurement and evaluation activities.

Major challenges exist however in the implementation of such architectures and architectural features. Issues of the changing environment, the cultural differences and ambiguity and the measurement of success are all key areas of required definition and system thinking before consistent solutions become available.

A model of system development appropriate to the scale of the problem facing designers is proposed in the 5 Column Model, where the whole acts as an over-arching synthetic environment enabling the development of architectures - organisations of resource - that are inclusive of all the pertinent components. The 5 Column Model enables a view to be taken by all stakeholders to the problem of the entire problem from capability need to solution implementation in a way that enables their position in the system to be well defined, the interactions and interfaces to be well specified and the appropriate resource organisations initiated. In addition, the model also enables the supplier - for example in the form of a Prime Contractor - to recognise his position and responsibilities in the development cycle.

The model is also well suited to the structures of the UK Smart Acquisition initiative in that it offers a means whereby incremental acquisition, technology insertion and capability upgrade can be evaluated in a coherent and consistent environment - thus enabling development of a comprehensive integrated Through Life Management Plan.

The successful development and implementation of Network Enabled Capability initiatives will dictate a breaking down of artificial barriers to the provision of operational effectiveness. The architectures inherent within an implemented Network Centric Warfare operation will need to be versatile and adaptable to support the multiplicity of desired effects and operations. It is offered that the Reaction Chamber model for Systems Engineering is sufficiently scalable to support a Defence wide view of capability provision through the detailed integration of all defence acquisition activities and programmes. The tail of this model and the required system evaluation and partnering essential to its successful implementation has been initially demonstrated through the UK NITEworks programme.

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