Adaptive Use of Networks to Generate an Adaptive Task Force

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1 Introduction

Today's defense missions are complex endeavors which are characterized by a large number of disparate entities that include not only various military units but also civil authorities, multi-national and international organizations, non-governmental organizations, contractors, and private volunteer organizations. The effects of interest go far beyond military effects to include social, political, and economic effects. The nature of the participants makes the collective action space complex while the multi-domain effects space also contains complex interactions among effects of various type. In addition, the relationships between and among the action and effects spaces and the multiple scales, in particular multiple timescales, that are involved in these relations further contribute to the complexity of the endeavor[1].

Numerous publications[2] argue that forces as a whole, and their command and control in particular, need to put more emphasis on adaptive properties in order to cope with the complexity and the uncertainties that are part of such endeavors. This paper reflects the thinking of both TNO from the Netherlands and DSTO from Australia about this subject. We recognize that in large organizations such as defense forces, adaptive properties during complex operations do not in general arise spontaneously. Individuals may be inherently adaptive, but organizations are more naturally conservative and often stifle innovation and non-conforming risk-takers. It is necessary therefore to put effort into articulating what we really aspire to in terms of organizational adaptivity, and examining how it may be achieved.

Moreover, we observe that western nations' military forces are still largely structured for traditional conflicts even though participating in complex endeavors is their main business most of the time. While military visionaries do realize that changes are necessary, the discussion about these changes remains at a superficial level and the nature of the changes required is still not very well understood. As a result, the transformation processes needed to implement these changes are slow.

In this paper we choose to focus on a key but relatively small portion of this problem space in order to achieve a certain level of depth. In particular, we address how to foster the desired operational adaptivity properties of the force, in the context of Force Generation, i.e. the process of building of a particular task force to be deployed, from elements in the parent force.

The desired adaptivity properties and how to engender them, will be developed on the twin bases of DSTO's conceptual framework for adaptation[3] and of TNO's concept of a command and control organization as three intertwined networks of social, information and ICT elements[4]. The central ideas of this paper are to identify practical approaches to generate the kinds of adaptive forces we need through deliberate fostering of appropriate interlinked adaptive processes in the three networks during the Force Generation process, and through growing and adapting those networks so as to empower and suuport those adaptive processes.

The structure of the paper therefore commences with brief recapitulations of the conceptual framework for adaptation in Section 2, and the three interlinked networks through which C2 is exercised in Section 3, together with a brief discussion of the relationships between the networks and adaptation.

In Section 4 we then examine the domain of Force Generation as the central linking piece between Force Development[5], and Force Employment. We explore here the relationships between these domains, in particular tracing how adaptive properties result from decisions and processes in each. We then take a biological diversion in Section 5, to examine the analogies between these domains and nature's adaptive processes of evolution, development and learning, in order to discuss a basis for identifying what kinds of decisions should be made in each domain, and what consequences flow from this.

In Section 6 we then concentrate on Force Generation, and discuss the intended outcomes of this stage – an effective deployable force with the desired adaptivity properties - and the key processes that influence these outcomes. We then draw these arguments together in Section 7 to recap how adaptation can shape the developing networks within the Force Generation phase to foster the intended outcomes and summarize our recommendations for implementation and for further research.

2 The conceptual framework for adaptation

Adaptation is a very general and abstract concept which can be instantiated in myriad ways. It includes all the ways in which living or engineered systems might improve their success or fitness for purpose. Thus as a result of adaptation, systems become better able to manage the complex problems posed by their environment.

Its key features are [1] the presence of an implicit or explicit notion of fitness, from which yardsticks are derived to select those proposed changes to the system which are likely to improve the system's fitness, [2] the encoding of useful information into the system, and [3] iteration of a *change – evaluate – select – implement* cycle.

Learning, engineering development, evolution, the development of immunity to disease, creative problem-solving and the distributed functioning of markets are all examples of adaptation. Adaptation is attractive because it enables a system to deal with complex problems, to generate useful new design features, to track dynamic change in the system's environment and adapt so as to remain successful, and to develop effective cooperative strategies with other systems to solve shared problems that are beyond the capacity of any of them alone. Moreover, it does not require detailed knowledge to develop solutions because it doesn't aim to achieve a solution in one attempt. Iteration permits starting with a partial or poor solution and improving it over time. However adaptation is not a silver bullet – it is not guaranteed to work for all situations, nor is it necessarily easy to exploit even in appropriate situations.

The ways in which possible system variations are generated can vary from random and highly parallel (as in evolution), to purposeful and serial (as in engineering development). How and where information is encoded varies from connection patterns in neural synapses for learning, to external data repositories and codified procedures in human cultures. Similarly, the ways in which variations are evaluated and selected can take many forms, from the consequences of direct experiential feedback to decisions based on sophisticated modeling. When a variation is selected for, there are further choices about how it is implemented – whether replacing or adding to an earlier form, adopted locally or disseminated widely and so on. Similarly variations that are selected against might be thoroughly eradicated or retained with lower propensities for their use. These and many other choices lead us to distinguish a number of types of adaptation, of which learning, evolution and the development of culture are important examples.

All in all, there is a very large number of parameters[6] required to specify a particular instance of adaptation – leading to two major consequences: there is a vast space of possibilities to exploit adaptation, and doing so is far from trivial since success depends on the many parameters being coherent[i].

The conceptual framework for adaptation[7] developed by DSTO is designed to clarify this space of possibilities, to generate a wider range of valuable adaptive options, and to assist defense planners and decision makers in the challenging task of making fuller use of these possibilities.

In addition to the types mentioned above, the framework makes a number of further detailed distinctions, creating the dimensions of the possibility space.

The next set of distinctions treats the adaptation process as a 'black box' and only looks at the result of the adaptation in terms of its impact on the system's behavior. Here we consider adaptation as generating a change in the system as a response to a stimulus, and hence classify the possibilities by the nature and scale of the stimulus and of the needed response. This leads us to identifying four classes of adaptation and helps us think about what we want in the way of adaptive properties:

1. ***Flexibility***: *Stimulus = External changes with long timescales and wide effect-scales*. Describes the ability to be effective across a range of unanticipated tasks, situations, and conditions across different future contexts – i.e. the structure and capability of the force can be reconfigured in different ways to do different things, under different sets of conditions

2. ***Resilience***: *Stimulus = Internal changes (damage) occurring over fast timescales and various effect-scales*. Describes the ability to recover from or adjust to misfortune/damage, and to degrade gracefully under attack or as a result of partial failure – i.e. the core functions of the system continue to achieve essential levels of capability when individual elements are disabled one or more at a time.

3. ***Responsiveness***: *Stimulus = External changes occurring over fast timescales and local effect-scales.* Describes context-appropriate behavior reacting to changes in the environment in a timely manner – i.e. when new threats or opportunities arise while executing a set of strategies, responsiveness is the capacity to recognize and deal with them as effectively as if there had been ample time to plan and prepare for them.

4. ***Agility***: *Stimulus = Internal and/or external changes occurring over intermediate timescales and wide effect-scales that decrease the validity of a current course of action.* Describes the ability to recognize when to shift from one strategy to another and to do so easily – producing a rapid change of tack to more effective behaviors.

A third set of distinctions looks inside the 'black box' and relates to what part of the system is able to change. Noting that the basic functions of any generic adaptive system are sensing, processing and acting, we begin with a system that has just those three functions. As we progress through a discussion of the levels of adaptation we add the details needed to introduce variation and fitness-linked selection successively into:

Level 1. the parameters that characterize the operation of the existing sense, process, and act capabilities of the system, - i.e. at the ***'action'*** level – creating a more contextually appropriate series of adaptive actions in the world, but within the constraints of existing sense, process and act capabilities;

[i] We note that living systems have taken a bootstrapping approach of using their current adaptation capabilities to solve this complex problem of designing more successful adaptive processes. Thus the evolvability of living organisms has itself evolved over time, the capacity to learn has risen through an evolutionary process, and has led to an ability to 'learn to learn'.

Level 2. the parameters that determine the scope of the sense, process, and act capabilities of the system – i.e. at the ***'learning'*** system level – using adaptation to change or expand sense, process and act capabilities in useful ways, but thereby introducing the additional functions needed to create variation in those capabilities, and to evaluate their fitness impact and select those that are useful;

Level 3. the parameters that determine the effectiveness of the learning mechanism – i.e. at the ***'learning-to-learn***' system level – using adaptation on the learning mechanisms themselves (the new functions in 2), and therefore extending those functions to act on themselves, thus improving the way in which adaptive actions are produced;

Level 4. the internalized selection criteria – i.e. at the ***'defining success'*** level – applying adaptation to the difficult problem of articulating and revising sufficiently precise and actionable measures of success, and therefore extending the functions in 2 and 3 to act on the internalized selection criteria themselves, noting that in order to achieve this it will be necessary to have access to some other more accurate measures of success – usually only available in slow time and in retrospect.

Jumping now to a system-of-systems viewpoint, we recognize that each component system can adapt via the previous four levels within the constraints of its resources, roles and responsibilities, but these constraints are themselves variables at the system-of-systems level, and therefore potential targets for adaptation. So we add:

Level 5. the parameters that determine the distribution of roles, resources, authorities and responsibilities between the component systems of a system of interacting adaptive systems, - i.e. at the 'co-adaptation' level – applying adaptation to the interactions between multiple adaptive mechanisms via the parameters describing their relationships.

In summary, if we think of ***action*** level adaptation as tuning a given system, and ***learning*** level adaptation as changing the system, then ***learning-to-learn*** seeks to improve the ability to change the system in useful ways. Together, these three levels enable the system to drive towards regions of higher success (as internalized by the selection criteria) in a generalized fitness landscape, while ***defining success*** calibrates the direction-setting mechanisms – the internalized fitness criteria – by which the system is steered. Finally, we can think of ***co-adaptation*** as changing the way we use our many interacting and adapting systems.

This set of distinctions helps us think about what kinds of adaptive properties we want to foster, how to improve a particular adaptive property, and what aspects of the system might be changed in order to do so.

Each of the types, classes and levels of adaptation can also be applied at different scales – from the level of an individual human, or a single self-contained system, through small teams and larger groupings up to organizations, distributed systems-of-systems and full scale enterprises. So the last set of distinctions addresses the scale at which adaptation is operating, directing our attention to scan across the many places where we may need adaptive behavior.

A related distinction in military terms is between:

- effectiveness in given tasks,
- effectiveness at the mission level – which requires the ability to choose the right mission objectives and the right tasks to achieve them, and to change tasks adaptively as required,
- effectiveness at the operational level – which requires the ability to choose the right operational objectives and the right missions to achieve them and to adapt the missions as required, and
- effectiveness at the endeavor level – which requires the ability to define the overall measures of success and failure for the intervention, to design the right operations, and to adaptively refine both as called for by the developing circumstances and understanding of the situation.

Each of these aspects invokes adaptation, but at different scales, and requires different information, decision rights, action options and support systems.

The space defined by all these distinctions (which could be laid out on 'axes') contains a large number of opportunities to exploit adaptation, of which a few are already well understood and utilised, but many others barely recognized and unexplored.

3 Three important networks of Command and Control

A command and control system can be considered as a network of three intertwined networks as discussed in an earlier paper[8]. These networks are a social, an information and an ICT network. They will be discussed below.

3.1 Social networks

People work in organized social arrangements, such as in sections, units, departments, projects and teams. Besides the formally organized linkages, people have many other connections to other people in and outside their own

organization. Formal and informal linkages between people together form the social networks which provide the basis for behaviors of an organization or group of organizations. New organizational concepts, such as networked approaches in defense and in business, are being developed to exploit the powers of social networks. They are based on the assumption that richly linked people and clusters of people are better able to develop shared situation awareness, solve unusual problems, synchronize activities and develop trust without centralized control.

Social networks are an important instrument to exploit the various aspects of adaptivity as discussed in the previous chapter. The ability of humans and groups of humans to reorganize their formal and informal networks of relations has proven to be a powerful tool to deal with evolving situations. On top of revelations in recent reviews[9] that there is a huge gap between what we need to know about social networks and the primitive state of our fundamental knowledge to ensure the smooth working of networked C2, there is also a lack of fundamental knowledge about factors of social networks that hinder or stimulate the adaptivity aspects. We suspect that decisions in the design of the formal organizational structures, policies and procedures and issues like incentive structures can influence the adaptivity opportunities, but hardly have evidence which exact characteristics result in better adaptivity.

3.2 Information Networks

Adaptivity of social networks can also be stimulated or restricted by the supporting information networks. Logically, the nodes of an information network represent perceptions of (abstract or concrete) real-world concepts while the edges represent relationships among the nodes. Both nodes and edges can have attributes. Philosophically, the information network exists irrespective of whether or not there is a concrete representation. It is obvious however, that a concrete representation of the information network is indispensable in complex military operations. This explicit representation typically resides in various information systems and databases, although one should not forget that a lot of information is implicit and resides in the human cognitive domain. This is true for the nodes but also for the relations between the nodes where the humans often form the linking pin between nodes.

The information network is an expression of the operational situation. It creates the ability to share information between different players. As part of the main challenge to ensure that the right information is available at the right time in the right format to the right person to the right use, without causing information overload, complex endeavors require information networks to be adaptive in order to represent the evolving knowledge of the dynamic situation. The challenge is to leave the options open (long) enough to add, change and delete information nodes and relations in order to represent an evolving understanding of the situation. An understanding and a corresponding information network that has characteristics that are hard to predict when the information systems and the databases are fielded. The characteristics have to do with the information elements, the relations between them, varying levels of detail for various user groups, different levels of required detail for different parts of the information space, different requirements for the presentation of the information and last but not least multiple levels of security depending on the user group.

A particular aspect of information systems to note is the fact that social networks in complex endeavors are complex in themselves and require a model representation in the information domain in order to be understood by the various actors.

Current information systems and databases are not designed with the required adaptivity in mind. Even worse, they are still struggling with more fundamental problems of stove pipes, lack of interoperability and the limitation of nodes that reside in the traditional military domain, without taking into account other perspectives like economics, health care, etc. that are of increasing importance in modern operations. It can be concluded that more fundamental approaches are needed to design information architectures for adaptivity.

3.3 ICT-Network

The ICT infrastructure is the layer of the information architecture that provides services for interaction and exchange of data. These services can be used by humans or information systems or by combinations of both. Given the important roles of interaction and information exchange, the criticality of the ICT infrastructure is higher than ever before. The adaptivity of the ICT infrastructure must be very high as well. First of all to reflect the adaptivity of the social network and the information network and secondly to cope with physical, environmental and security limitations. On top of the obvious challenges of military environments, the particular challenge we note here is the fact that the large number of heterogeneous, i.e. not only military, actors in a complex endeavor, have an ever increasing need to collaborate and thus exchange information and thus need to be provided with data exchange services, in a secure and adaptive manner to reflect the dynamic evolving needs of this social, mutual interdependent network of actors.

Current ICT-networks again are not designed with the required adaptivity in mind. The are still very stove-piped and lack flexibility. Although it is recognized that complex endeavors require ICT-networks that span multiple organizations, national units are still to struggling to deal with their own stove piped systems.

3.4 Interactions between the Three Networks and Adaptation

A natural question to ask now, is how these networks relate to various processes of adaptation – how do they support, enable or indeed interfere with them, and in the other direction, how various adaptive processes contribute to the growth and evolution of the networks themselves.

Adaptive processes consist of a number of subprocesses closely linked in a cycle: perception of stimulus; variation (generation of options), interaction and feedback (assessment of options), selection (implementation of chosen options), and monitoring which then provides the next stimulus.

Let us look at one example. Consider a resilience adaptive process. Firstly, it needs to be monitoring the status and health of all the essential capability it is responsible for, and when a threatened or actual loss is perceived then that is the stimulus to invoke the rest of the resilience process. The next step is to generate a range of options to avert the threat, neutralize it, repair the damage, mitigate consequences and redistribute or redefine tasks to deal with the loss. The options generated have to be assessed for impacts on each dimension of effectiveness, feasibility, cost, risks and so on, using some kind of "what if?" support e.g. modeling, simulation-based experimentation or experience-based judgment. These assessments have to support a decision process that can choose the option that is expected to yield the best overall fitness. When particular options are chosen and implemented, additional specific sensing may need to be put in place to monitor for actual impacts on fitness, and so enable further adaptive responses as needed.

All these sub-processes need to be integrated into a smoothly functioning loop with minimal delays, efficient information transfer, transparency and linkages to other adaptive processes to provide failsafe backups, learning and any other adaptive adjustments needed in the force as a result of the options implemented.

The most obvious role of networks in all of this is to provide the needed connectivity between each step, and between each linked adaptive process, but in fact there is a lot more that networks could do to increase the effectiveness of such an adaptive process.

While there will be identifiable individuals primarily responsible for each step, and there will be a formal allocation of resources allocated to support their roles, in practice they will often considerably augment the quality of their performance by drawing on the informal resources of their social networks. Admittedly, there is an *ad hoc* aspect to this and the possibility of slowing the pace of response. However the reality is that leveraging their networks is already an important factor in how individuals actually operate, and in many respects, a major contributor to their effectiveness.

What we would like to point to here, is the possibility of this *ad hoc* use of networks being a start point for adaptation at Levels 2, 3, 4 and 5 for the organization to grow an improved resilience capability, and so get beyond its current limitations.

In other words, when individuals discover connections in their networks that enhance their ability to perform their role in an adaptive process (such as the one taken as an example here), these discoveries could be treated not just as once-off fixes, or even just as a Level 2 Learning adaptation by the individual concerned, but rather as the raw variations being fed into a Level 2 Learning mechanism of the whole organization.

This would of course require there to be a Level 2 Learning mechanism operating in the organization – in other words, sub-processes to collect and evaluate such spontaneous variations and select those that are of sufficient organizational value, implement them, and put in place additional monitoring as required in order to confirm the value of the changes made, or to stimulate further adaptive changes if needed. Furthermore, such an organizational learning process presupposes a well-enough defined yardstick of resilience, so that it can be judged whether changes do in fact improve the organization's resilience.

Similarly, we could examine other adaptive processes addressing flexibility or agility etc, at various scales and levels – and the sum total of all their potential contributions to not only current effectiveness of the operational force in its dynamic environment, but to organizational learning across the entire force.

So on the one hand, we have the individuals' use of their own social networks, and the personal learning that they thereby engage in, leading to their becoming better aware of relevant indicators that should be watched, and of options and factors that need to be considered, and better able to wield influence in the organization to achieve outcomes that contribute to the effectiveness of the adaptive process they are a part of. These individual adaptive uses of networks enhance the quality of condition monitoring, option generation, assessment, and implementation. But they do not necessarily change the networks themselves, nor do they necessarily change the formal allocation of resources to the various sub-processes of the adaptive mechanism in question. A newly posted in individual would have to find his/her own ways of adapting to the demands of his/her role, as would other individuals playing similar roles in other parts of the organization.

On the other hand, if the organization is able to learn from such individual adaptations occurring in its various adaptive processes. Then the social, information and ICT networks could rapidly evolve to better serve those adaptive processes, and the processes themselves could evolve to become more and more effective, and successive postings could better benefit from the learning of their predecessors, and indeed of their colleagues across the whole force. This path will be further explored in the following sections.

4 Force-level Development, Generation and Employment

We consider now how forces come to be, and how they come to be employed. Our present focus is on Force Generation, but of course this operates within a larger construct.

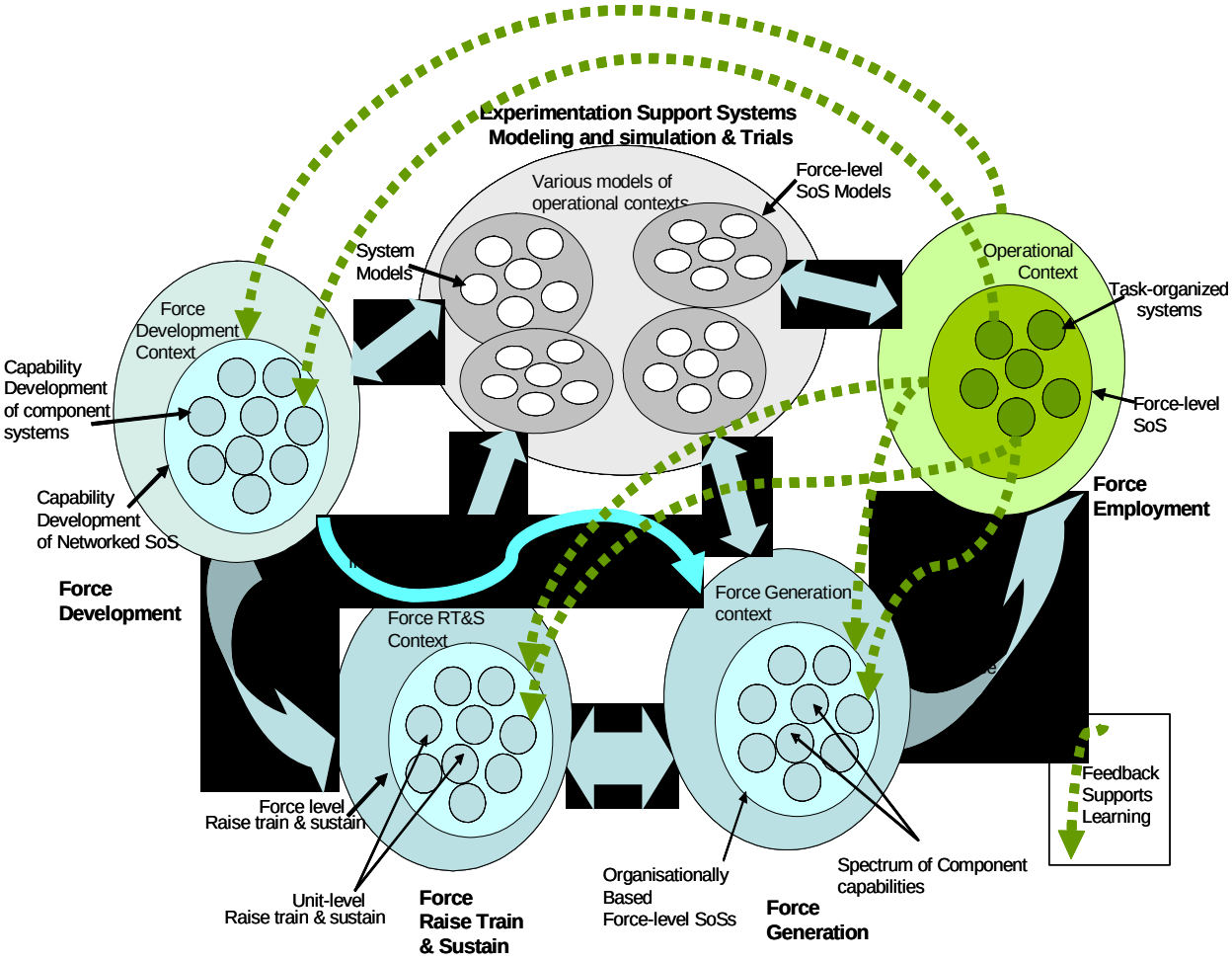

Figure 1: Simplified schematic of the various stages of developing, maintaining and employing a defence force, demonstrating the relationship of the force generation process to the other stages. The diagram also highlights the role of experimentation (such as trials, modelling and simulation) to support exploration, development and evaluation of options in each stage. Feedback from operational experience at both unit level and force level is important to support rapid learning and the adaptation of capability, doctrine and training. When needed, accelerated capability development can bypass some of the usual processes to provide rapid technology insertion into the generation of operational forces. (Diagram adapted from an earlier paper[10])

A schematic of the domains in the development and employment of a nation's forces is illustrated in figure 1 above. It demonstrates the relationships between the domains, and in particular the role of Force Generation in drawing on the existing force, to design and create tailored deployable forces for operational requirements as they arise. The existing force is managed by the Raise, Train and Sustain systems of the force, and is continuously augmented by upgraded or new capabilities produced by the Force Development systems.

This Force Development domain includes the development and definition of requirements, and the design, development and acquisition of not only materiel, facilities, information systems and infrastructures, but also of doctrine, organizational structures and processes. Together with the Force Raise, Train and Sustain domain, where recruitment, training and day-to-day management of the standing force resides, it creates, replenishes and updates the elements of the parent force.

The capabilities of the parent force both contribute to and constrain what an actual deployed force can do, so of course consideration of possible future operations will place requirements on the parent force and thus on its capability development domain. However, our particular interest in this paper is in the subset of requirements that stem from consideration of the roles that the ICT, information and social networks play in Force Generation and Force Employment.

The Force Generation domain is the bridge between the parent forces and systems, and the deployed operational forces. In Section 6 we will examine in some detail how this domain goes about selection of force elements and structuring, integrating, training them up to the required level of readiness for deployment.

The Force Employment domain is where "the rubber hits the road". The value of the other domains and systems is derived from how they support and enable effective operations, and their impact on the quality, and attendant cost and risks. There is also a flow in the other direction. Since Force Employment is the rationale and endpoint of everything else, feedback from individual, unit and force levels in this domain about what has or has not worked, and

ideas about what might or might not work, are very valuable, and need to be processed to be channeled to the relevant domain unit or SoS for evaluation and processing to enable organizational learning.

All the domains function continuously in parallel and must inform and interact with each other appropriately to enable overall coherence of the entire enterprise. Of course at any given time, there can be more than one collection of force elements in an operational employment or a force generation phase.

Because all these domains are complex and challenging, they all need experimentation support to help generate, test, evolve and validate new concepts. These experimentation environments may include the full spectrum of ways in which ideas can be generated and tested, and can range from low resolution, fast and local techniques, to high fidelity simulation and field experiments, and access to powerful reachback support environments. Note that the diagram is not meant to imply that there is a single physical centre of experimentation supporting all the domains, but rather that there is a logical function of experimentation support, and that there needs to be consistency and coherence in how it is provided across the enterprise.

5 A Biological Analogy – Evolution, Development and Learning

Returning now to our understanding of adaptation, informed by study of how it operates in natural living systems, we draw the following analogies[ii]. Living organisms are the products of three quite distinct forms of adaptation – evolution, development and learning, which bear some conceptual resemblance to the domains we have discussed.

Evolution: The basic design of an organism is the result of the evolutionary history of its species - a long timescale process, whose output can be thought of as in 3 forms: design information (the genome), initial conditions[11], and an environmental and ecological niche[12] in which it will live.

Development: This set of outputs creates the potential for a spectrum of organisms, but the actual organism that emerges from the next phase, development, is the result of complex self-organizing processes and interactions between the genome and the development environment, and to a lesser extent, the external environment including aspects of the ecological niche. Development occurs in a robust and repeatable way over a well-defined timescale, and its output is a particular functioning organism, that has the potential for a spectrum of life trajectories and particular properties.

Lifecycle learning: As the organism pursues its particular lifecycle trajectory within its niche, its potential properties will be realized into particular specific properties, depending on the details of its interactions and environment and the learning opportunities presented. The organism's experiences up to any point in its lifecycle modify its potential for further realization of properties. From the organism's perspective, its lifecycle output consists of its successes in thriving and reproducing, but from the perspective of the species, the organism's lifecycle output consists of contributions to shaping the design information, initial conditions and ecological niche of its successors. For species with culture, the organism's learning may also be culturally transmitted to its peers and successors.

What is relevant about this biological diversion, is consideration of what sorts of design decisions get made in each stage, and why.

A very large part of the genetic design information pertains to very low-level functions (metabolism, cellular housekeeping etc) on which higher-level capabilities are based, and to orchestrating the procedures for the next phase – development – which builds the higher-level, better adapted capabilities, largely through self-organization processes rather than in a detailed prescriptive fashion. The design features that tend to be specified through evolution are those that are costly to build (in time, energy and materials) or on which many others depend. Since such features are costly to change during the organism's lifecycle, they tend to be fixed, and therefore need to be very robust across a wide range of conditions likely to be encountered. Evolution is the ideal adaptation mechanism for extensive testing across many contexts and lifetimes, and for reliable transmission of the design information.

During development the adaptation largely consists of interactions between self-organization processes to coordinate them, with some adaptation to contextual information, mostly from the internal development environment. The design decisions that get made in this phase are mostly in the category of fleshing out many details which genetic information does not specify. The details that are well-handled by this approach are those where it is the local context that matters most for determining the actual values – e.g. the physical dimensions of co-developing bone, muscle, neural and vascular systems that need to connect and work together. A particular class of self-organizing process that is very important in the coordination of development is what Kirschner and Gerhart[13] have called exploratory processes. These are processes that generate a large variety of states, and provide a mechanism for selecting those that best meet the local need. Larger-scale coordination is achieved by a combination of 'global' signaling across the developing organism, interacting with local regulation. These are very efficient, robust and compact processes, able to reliably generate a wide variety of particular organisms from a basic design.

Finally, the design decisions that get made during the organism's lifecycle are determined by the degrees of freedom that have been left open by the preceding stages. This in itself is an important design decision, essentially determined

[ii] This is a cursory and simplified discussion, overlooking many important details and instructive exceptions.

in those preceding stages. The extent of lifecycle design freedom varies widely between species, but the variation can be understood by considering the stability of the environment and the strength of the selection pressures on the species. Those that occupy very stable niches can afford to evolve fixed and specialized behavior. More dynamically variable niches call for the ability to discover and learn what works, and for behavioral choices in real time in response to the actual conditions the organism finds itself in.

Choosing and learning can be thought of as design decisions on a fast timescale, because they correspond to changed internal configurations, i.e. they modify details of the organism's actual design to increase its chances of immediate or future success.

Obviously it is not sufficient to just leave design parameters undetermined. There will only be adaptive benefit if those freedoms are accompanied by adaptive processes that can exploit them. There are two main adaptive strategies we observe in living systems for success in a complex dynamic environment. One is to produce a large number of diverse offspring with low investment in each, with the expectation that most will fail, but some will succeed no matter what particular future unfolds. The other is to invest more significant resources in a smaller number of much more complex and capable offspring, with the ability to learn. What the latter strategy achieves is more flexibility, responsiveness and agility in behavior within individuals, while the former achieves those properties only at the population level. But adopting either strategy requires particular design choices to have been made at earlier stages.

In general, learning and behavioral choices will require more capability in sensing, information processing and action, while the more powerful learning-to-learn process will also require variety and selection in these functions.

In addition, as noted above, there is feedback from the lifecycles of individuals organisms into design decisions for future organisms.

The analogies with our Force Development, Generation and Employment domains should by now be evident. If Force Generation to produce a particular deployable force corresponds to the development of a particular organism, then the Force Employment domain is the parallel of the organism's lifecycle, the Force Development domain maps onto the species' evolution, and the Force Raise, Train and Sustain domain corresponds to the organism's parent population living in its environmental niche. Lifecycle feedback to future design relates to organizational learning from current operations.

While we are certainly not suggesting a prescriptive interpretation of the analogy, we can draw some insights from this discussion to reconsider how we decide which design decisions get made in which domain. Since we are not bound by the constraints of evolutionary or self-organizing processes, we can also explore ways in which we may depart from the biological dynamics in order to extend the boundary of what we can achieve and cope with.

Firstly, we observe that this discussion paints a more comprehensive picture of how adaptive properties arise, what shape they take and when and where they operate. There is a trade-off between making design decisions at the last possible moment (keeping options open to increase adaptive range) and the costs and risks such a posture might entail (a greater decision burden placed on the operational domain, risks of poor decisions, and the greater cost of providing the extra sense, process and act options needed to take advantage of the adaptive range etc).

Working backwards from the Force Employment domain, if we wish to maximize an operational force's adaptive properties for complex endeavors, then we must ensure two things: that the necessary design degrees of freedom are left open in the preceding stages, and that the necessary adaptive processes are facilitated by the design choices made in those stages.

Working forwards from the Force Development domain, we might explore the proposition that this domain should only determine those design features that meet the same conditions we noted above, of being costly to build or of having many other design decisions dependent on them. This interesting discussion will be developed in a forthcoming paper[14].

Rather here we will take the middle perspective of Force Generation, which we now turn to.

6 The Force Generation Process

6.1 Methodology

We now consider the formation of a military force that will be employed in a complex endeavor (e.g. a rotation in an ongoing military intervention) and how it will be formed from the nation's organic military capabilities (the parent force).

The inputs to this process should stem from both the operational domain (what is needed) and from the parent force (what is possible). However what is needed depends on the stratagem for engagement, which in turn depends on an adequate understanding of what is likely to be quite a complex situation, and on what is perceived to be acceptable, to best serve the nation's interests, and to be possible – introducing a perplexing circularity. Thus overall, the task of generating an appropriate force is a complex design challenge. It entails both *system design* of the system-of-systems which will be deployed, as a force mix with its processes, capabilities and organizational structures, and *operational design* of the intervention, with a strategy, measures of success and failure, objectives, relationships and constraints.

We believe there is a close parallel between the problems of operational design and of system design. Both can be thought of as seeking to create effective interventions in complex systems (others' or our own), and in both cases there are a large number of possibilities, and interdependent multi-dimensional measures of success and failure at multiple scales.

Further, our interventions play out through complex causal and influence networks of people, systems, processes and relationships, interacting with a large number of contingent and uncontrollable factors to produce outcomes that will contribute to success or failure. This applies to both system interventions (e.g. force generation decisions) and operational interventions (e.g. strategy and course of action decisions). But we do acknowledge that while causal and influence networks are difficult enough to explore and understand in our own systems, they are orders of magnitude more difficult in the case where we are trying to understand and influence complex evolving societies with multiple agents within which hostile situations occur.

However, in spite of the clear differences between the two problems, the similarities suggest that in both cases we have to take an adaptive approach to our interventions, i.e. seek to learn about the dynamics of the causal and influence networks, use our growing understanding to evolve a strategy for our intervention, and then, within the context of that strategy, iteratively generate and evaluate specific intervention options, and monitor the consequences of those selected for implementation, using that feedback to review and further evolve the understanding of the causal and influence networks, and hence continue to evolve the strategy and the specific interventions themselves. In practice, to achieve consistency and resolve the circularity, the interdependent design processes of operation and system will have to co-evolve.

Such a methodology sits well with the general tenor of our approach, which is to confront complexity where we find it, by embracing and exploiting adaptivity. In particular, we note that when applied to our engagement with adversary systems, this methodology inherently creates the mechanisms for agility and responsiveness as we have defined them, while when applied to our force generation processes, it similarly enables flexibility and resilience.

6.2 Objectives

The intended output of this process is a task force that will be able to achieve success in the particular complex endeavor for which it was created. In the light of the arguments in the preceding sections, we assert that requires the task force to be *effective*, *integrated, adaptive*, *deployable*, *sustainable,* and able to support *organizational learning*, in particular for subsequent rotations and operations. We now expand on what is implied by these terms.

Effective

A principal focus of the Force Generation domain is of course to enable and foster the future effectiveness of the force it is generating, through appropriate mission familiarization, facilitating learning from current and recent operations, collective training, mission-relevant exercises and feedback. This implies that effectiveness, success and failure measures for the intervention, and their dependent hierarchy of measures, can be well enough defined during the force generation phase to guide these effectiveness-building processes.

However, defining success and failure measures in complex endeavors is problematic because of the multiple scales and multiple dimensions of the outcome space and the multiple perspectives on the relative importance of different aspects. Even if different parties agree on higher-level statements about success and failure, they can disagree about how to derive mission objectives from them, because of differences in their understanding of what is possible, or in their concept of how achieving those objectives would contribute to the higher level outcomes. Moreover, as the situation develops, the initial success and failure measures may become less relevant and will therefore need to be revised.

Assessment of the potential effectiveness of the task force in its build-up phase pre-deployment, and of its actual effectiveness during its operational tour of duty, therefore depends on how success and failure, and their dependent measures, are defined. Objective measures of the state, and of the dynamic behavior, of the situation will of course be monitored, and assessments will be made by many different parties as to whether the intervention is on the right track or not. These progress assessments may come to quite different conclusions, depending on the perceptions and values of those making them, but in general, ultimate success or failure will only be apparent in hindsight well after the intervention has ended – although even then it is not always easy, or indeed possible, for analysts and historians to agree on its effectiveness.

Since interventions will rarely fully achieve their espoused measures of success, the notion of effectiveness must also take into account whether a task force could reasonably have been expected to do any better given the constraints in resources, the acceptable levels of risk, the understanding and information that was in principle available to them, and the weightings given to long term versus short term outcomes.

Given all this complexity one should not expect to be able to define success and failure unambiguously from the beginning, but rather accept that they will need to be evolved over the duration of the intervention. It is necessary therefore to keep track of changes in how success and failure are defined, how dependent lower-level objectives are derived, and how well these are being targeted by the current force construct and approach. This may well lead to needing changes in both, so the Force Generation domain should expect to remain engaged and to keep supporting

the ongoing adaptation of a task force after it is deployed, as well as concentrating on generating the following rotations, and leveraging the lessons drawn from the current and preceding rotations in the process.

Integrated

Task forces are rarely drawn from a single parent unit, so one of the challenges in force generation is forging a cohesive force from a disparate assembly of elements contributed from various parts of a much larger organization, with the necessary trust in each other's abilities, a sense of a shared collective identity and a willingness to cooperate to serve the overall intent. 'Integrated' also means that the task force is able to make the best use of its various elements resulting in a "sum that is greater than its parts" and is able to plan and act in a coherent way, so that actions and plans of one part will support the actions and plans of other parts.

Obviously there needs to be a process of *integration* within Force Generation in order for it to produce an *integrated* task force, and we would argue that adaptive team-building processes to foster development of the necessary relationships have an essential role in achieving integration.

While this discussion primarily addresses integration within the context of a specific task force for one rotation of an intervention, we also acknowledge the importance of extending the notion of coherence to apply across successive rotations, so that each builds on the foundation laid by its predecessors and seeks to amplify the successful outcomes of their actions. This requires a sense of cooperation and collective purpose which should be fostered by the Force Generation process, rather than the spirit of competition between rotations which naturally arises if force-level coherence over the intervention is not deliberately cultivated.

Adaptive

We have already discussed the power of adaptivity, and the spectrum of ways in which it can be exploited, in Section 2. In a complex endeavor it is evident that the task force must be able to recognize the need for change and make effective changes in a timely way. It must be able to maintain effective context-appropriate behavior across all the relevant dimensions of the situation, taking account of all the factors affecting its effectiveness at all scales. This will of course require many adaptive processes to be functioning, with rich information sources to feed them, the ability to analyze complex dynamics to generate and assess options, and the ability to evolve its relationships with other parties and learn from them to enlarge the space of effective options available.

Moreover, the task force must be able to improve how it does all these things, not only during the force generation process, but also continue to improve them over the course of the rotation. In one sense, the most important aspects to have locked in place during the Force Generation process are these second and third level Learning and Learning-to-Learn processes, since these will enable the Task Force to learn and adapt as they go, and rise to the challenges of the operational situation as it develops.

In a nutshell, we claim that all the classes, levels and scales of adaptivity discussed in Section 2 are of value in complex endeavors, and a primary objective of the Force Generation domain should be to facilitate the developing task force launch and orchestrate its adaptive processes.

Deployable

To be deployable, a task force must have met its Operational Levels of Capability (OLOC) as defined by its parent organization and the Force Generation domain, and be ready to move, with all the necessary support and transport requirements having been identified and met. On arrival in theatre, the rotation must be capable of standing up its structures and processes and participating in an effective handover / takeover from previous rotations within agreed timeframes. The Force Generation domain will be responsible for bringing the task force up to OLOC, transitioning it into theatre and ensuring all the support systems are in place and operational.

Sustainable

A task force is sustainable if the rate of utilization of consumable aspects of the force is consistent with the capacity of the support environment to sustain the minimum required OLOC (operational level of capability). It must be able to identify changes in the need and adapt the rate of replenishment as needed. Rates of utilization in real operational environments will not be steady in general. Unanticipated surges in activity and utilization must be accommodated by maintaining a certain amount of reserve capacity. But the reserve capacity must be restored after depletion if the force is to remain sustainable. This applies to personnel and the needs, as well as to equipment and supplies.

Supports organizational learning

Every operational tour in the Force Employment domain provides many occasions to learn about what works and what doesn't, how robust the force's systems and processes are, what could be improved, and what the results have been from earlier attempts to improve. These are plentiful and immensely valuable learning opportunities which must be recognized and mined for all they are worth if the force is to keep evolving and achieving high levels of effectiveness in the rapidly evolving complex environment in which we now operate. Such organizational learning represents a set of crucially important Level 2 adaptive processes at the scales of the whole force, and at various unit and sub-unit scales.

In Figure 1 we indicated some of the feedback paths from operational forces that would support such organizational learning, in each of the other domains and at each of the relevant scales. But for this feedback to be useful, it must be directed into the appropriate learning processes in each domain and scale, and those learning processes must of course be functioning completely. As described in section 2, the key aspects of a functioning adaptive process are [1] the yardsticks for fitness, [2] the recording of what is learned, and [3] iterative execution of a closed loop of change – evaluate – select – implement. The above discussion about how effectiveness is formulated and assessed is therefore critical to informing [1]. As for [2], where and how learned information is encoded can take many forms. Popular choices include publications, structural changes in organization, shared databases and incorporation into training material, doctrine and Standard Operating Procedures – but what matters is how well the system is able to use the encoded information to change its behavior in ways that increase its likely success.

The core of an adaptive process is always the cycle, [3], and the biggest pitfall in implementation for organizational-scale learning is that its sub-processes are widely dispersed across the organization – and therefore their tight integration into a smoothly functioning tight loop is problematic, to say the least. The most basic Level 2 organizational adaptation is therefore to ensure the existence and integrity of all the needed adaptive processes in the force, if necessary making changes to the information and ICT networks to improve connectivity and integration. Further, as discussed in Section 3.4, the evolution of these networks should be driven in part by the adaptive processes so that they become better able to support them.

Organizational learning also depends on stimulating and collecting relevant feedback from all scales of the force, and the ability to process it so as to extract relevant lessons, test and further develop those lessons as needed, and disseminate them appropriately throughout the force, as illustrated in Figure 2 below.

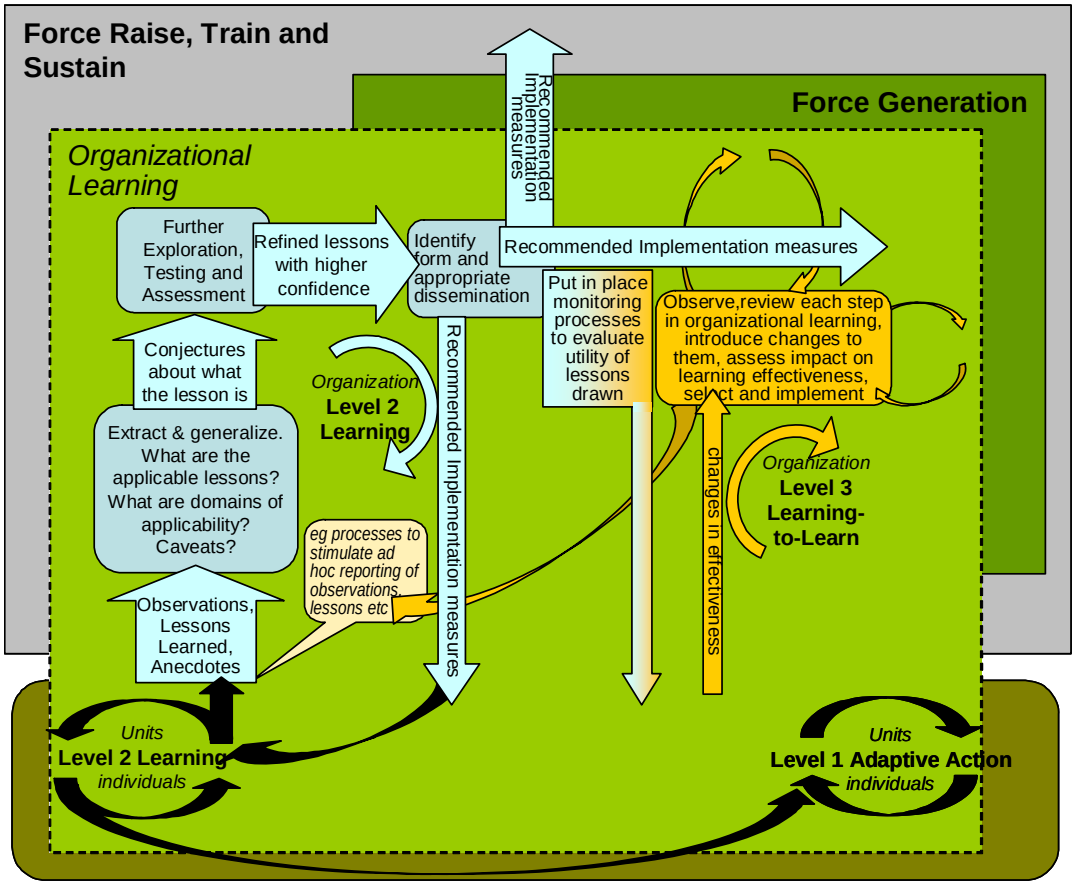

Figure 2: Organizational Learning from deployed operations depends on the existence of appropriate processes at multiple scales and within each force domain, plus the necessary links between them. Illustrated here are a subset of the needed processes and links: Level 2 Learning at the scales of individuals and units in deployed operations, with the outcomes of their learning feeding into their Level 1 Adaptive Action cycles; the Organizational Learning system spans the four domains of Figure 1 (Force Development is not shown here), and fosters the collection of feedback in the form of observations, lessons learned and anecdotes from individuals and units; it then processes them as shown in its Level 2 Learning cycle resulting in recommended implementation measures to be disseminated into each of the three domains shown; the utility of those measures then needs to be evaluated through putting appropriate monitoring in place (shown only for the Force Employment domain); this monitoring serves both the Level 2 adaptive refinement of the lessons and their implementation (shaded blue), and also Level 3 learning-to-Learn (shaded orange) for the organization; Level 3 adaptation addresses all aspects of organizational learning, and seeks to improve its quality as measured by its success in improving effectiveness in each domain. An example is shown of a Level 3 generated change to organizational learning, through introducing new processes to stimulate more or better reporting of relevant observations and lessons.

6.3 Detailed Requirements for Force Generation: Processes and Principles

We have so far proposed a methodological approach to Force Generation, described the inputs to the process, and its objectives as intended outputs. We now discuss in more detail what has to happen in the Force Generation stage.

The methodology of section 6.1 implies a number of nested simultaneous adaptive processes, initiated in a staggered fashion:

[1] Learning about the history and dynamics of the causal and influence networks in the situation;

[2] Co-evolving the intervention stratagem to influence the situation (the operational design) together with the force mix (the system design), in the light of the strategic objectives for intervention, and the available capability elements;

[3] Building the force to be deployed: assembling the force elements (concentration of force); deciding and implementing their command and teaming structures; integrating and training them; developing their understanding of the situation, of the mission, and through cross-briefs, of each other's capabilities (since elements are likely to be drawn from various parts of the parent force); evolving their operational concepts and procedures to suit the actual mission; and undertaking mission rehearsal exercises leading up to the actual deployment;

[4] Developing the networks and the relationships that the force to be deployed needs.

Figure 3 below shows a typical timeline for a series of successive rotations into an operational situation. Each rotation undergoes an extensive build-up phase pre-deployment, culminating in a successful Mission Rehearsal Exercise (MRE) and meeting all its readiness and OLOC criteria. It is then deployed, and following insertion, has to rapidly achieve an effective level of capability, while also participating in a hand-over/ take-over (unless it is the first rotation). In theatre training and various team-building and learning processes continue as opportunities permit and the situation requires, throughout the operation. Additional capability may be inserted during the rotation, and will need to be effectively integrated into the force, as well as adaptations made to cope with any losses or degradation of capability, and in response to significant changes in the situation, or in the understanding of the situation.

Throughout the rotation, the force is learning and adapting, and is documenting its observations and insights and preparing for its eventual hand over to the next rotation. It will also host reconnaissance and familiarization visits from the command team of the next rotation which is by that time, well into its own force generation phase.

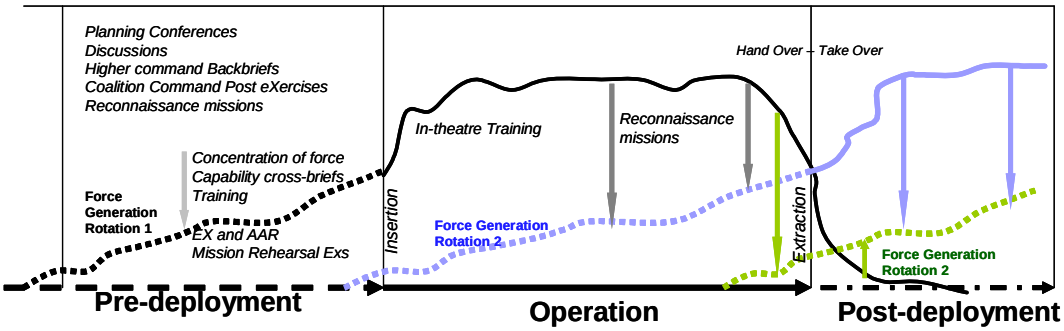

Figure 3: Timeline for a series of successive rotations into an operational sitution. The rotations are color-coded as black followed by blue, then green. The primary Force Generation phase for a given rotation is shown as a dotted line indicating the gradual growth of capability during the pre-deployment stage. Some of the typical activities in this period are indicated. See the text for additional details.

One of the features of Force Generation that springs out from Figure 3 is that there are always several forces to be dealt with simultaneously, at different stages of their own cycles. The Force Generation systems are therefor well-placed to facilitate the transfer of learning and adaptation between them. One mechanism that is already utilized is the reconnaissance visit by the command team of a force that is just being built up, to the current rotation in theatre. The hand-over – take-over process is another example.

Returning to the four adaptive loops listed above, we observe that there are various individuals, groups and stakeholders implied by the processes listed.

For example, loop [1] is aimed initially at the Commanding Officer (CO) of the force to be formed, since the CO will generally be the first individual identified for the force, and will have probably the most significant shaping influence on the subsequent loops. But as other members of the command team are identified and allocated to the developing force, they also need to participate in the iterative development of situational understanding.

Loop [1] is not a passive exercise. There will of course already be assets in place observing and collecting multi-modal information about the situation, but as the growing team engage more and more with Loop [1] and start developing their own mental models, they will also start asking focused questions to illuminate critical aspects, or to evaluate alternate views or options, which will generate new information requirements, or change the scope, resolution and priorities of existing ones. The overall collection plan therefore needs to be continuously evolving, and

therefore so do the information and ICT networks. In fact, Loop [4], and the opportunities to start shaping the evolution of the 3 networks, begins here.

As Loop [2] also begins, other groups and stakeholders come into play – senior leadership figures in all three domains of Figure 2, as well as the new CO, and the rest of the command team as they materialize. Between them these stakeholders represent the enterprise's understanding of what is required and of what is feasible, and they must collaborate to come up with the initial operational design and force design, and then to iteratively refine them.

Once again, the CO and command team will be engaged in shaping and influencing to put together the best force and operational design they can, and their use of their own social networks will help them to do that. As resources and connections are discovered to be valuable in this process, if they can be expected to have ongoing value, they should be included in the growth of the networks, including any necessary changes to user interfaces and process support tools to facilitate future users' ability to exploit them.

In a sense, Loop [3] has already begun when the CO is identified, but apart from the small handful of people initially involved, Loop [3] really takes off when the concentration of force occurs, over a very short period of time. The potential to grow the networks also rapidly increases as more connections are made with more systems, sources and people.

Within both Loops [2] and [3], the force generation process must first have access to, and then, be able to select the right elements, including personnel, equipment, but also the appropriate doctrine and TTP's, often drawn from widely different parts of the parent organization. The availability of information about these elements and the existence of particular social links may play critical roles in this selection process.

Recalling our discussion of Section 5, there is also the opportunity in this stage to protect the degrees of freedom that the force will need to deal adaptively with the unexpected and the complexity of the operational environment. This may extend to the composition of the force – for example being able to introduce additional and different capability elements as it is realized that they are needed, but also allowing the CO and command team to evolve their approach, ways of working, and measures of success. However, as pointed out in Section 5, preserving the freedom to make these choices also requires that the force is provided with the information and resources to support those decisions. Once again, it will be essential that they can make full use of the three networks we have described, and also direct their adaptive evolution.

We note that the force generation process must synthesize these elements while Loop [1] is in the intensive process of building understanding and acquiring awareness of the mission, and moreover, must deliver the training to achieve the required skills levels, integrate the technical systems and build the formal and informal social networks. Relations with former and current rotations and future coalition partners are again essential to ensure that lessons learned already are taken into account, and to build coherence across time and across the larger coalition.

In fact, coherence is one of the major challenges for the Force Generation process and the CO, especially fostering it within the developing force. Coherence is needed in a number of dimensions:

- Horizontally: so that actions by different force elements
  - should not undermine each others' objectives, and
  - in fact, should be synergistic by reinforcing each others' intents and key messages.
  - Thus, perceptions created in target populations will be of consistent rational actions.
- Vertically: actions at one level support actions at higher levels and vice versa.
- Temporally:
  - Expectations created in target populations are understood, recorded and actually monitored and supported so that successive rotations do not just dismiss or ignore them, and start afresh
  - there is also the issue of temporal coherence between linked adaptive processes – if one process is acting on a parameter or a significant contextal variable of the other, then it needs to be changing that parameter or variable at a much slower pace than the cycle rate of the affected adaptive process, else dynamic instabilities (chaotic swings in the variables affected by that adaptive process) may be expected to occur.

Obviously coherence is important in reducing friction and waste, and increasing effectiveness and motivation, however we have to acknowledge that it can only ever be partially achieved and needs to be continuously monitored and actively created through adaptive processes. Moreover, coherence can not be assessed instantaneously and can only be judged over appropriate timescales. So the adaptive processes that are intended to grow coherence can only do so at a certain pace, guided by the availability of feedback from assessments of coherence.

Finally, as we have already pointed out, the force generation process itself must be able to learn from previous rotations and from its own strengths and weaknesses in delivering these rotations, as suggested in Figures 1-3. By applying adaptation to the force generation program itself, we can expect to improve its ability to produce the most appropriate employed forces.

7 Conclusions: The Role of Networks in Generating Adaptive Forces

We have concentrated on the Force Generation domain in this paper, and in particular on the roles of adaptation and of the three evolving and intertwined networks, in producing an adaptive force. Our primary perspective has been the force of a single nation, which risks omitting some important dynamics, but the approach we have used is in principle generalizable to multi-national endeavors.

In focusing on the Force Generation domain we have aimed to identify both the adaptive properties needed in this domain to support organizational learning, and the adaptive properties it needs to deliver to the Force Employment domain.

We have dicussed a methodological approach to Force Generation that is grounded in adaptivity, and explicitly addresses the particular challenges of creating appropriate forces for complex endeavors.

We have noted the vital importance of leveraging the social, informational and ICT networks of the parent force, to facilitate selection of the right elements, to provide feedback of lessons to the parent force, and furthermore, to grow the deployable force's own networks and adaptively extend them as needed, by drawing on the social and professional connections that individuals have in their own parent force networks.

Throughout the paper we have pointed out many ways in which these networks can support and extend the capabilities of the developing force being generated for deployment, eg assisting the Force Generation process to:

- find and access existing information about force elements, their capabilities, their current dispositions and their plans;
- find and access the experiences of preceding rotations and sibling task forces;
- develop the necessary trust relationships with the relevant units and departments of the parent force in order to better integrate the contributed units and to enable flexibility in adapting to changes in the situation;
- provide feedback on the status and lessons learned of the force generation process itself, and thereby support its own learning;
- ensure lessons are turned into appropriate actionable implementation measures by the parent force; and
- utilize and adapt all the relevant DOTMLPF factors (Doctrine, Organization, Training, Material, Leadership, Personnel and Facilities) in the preparation of the force to be deployed, including
    - Tailoring of doctrine to the complex situation, adapting it as necessary and orchestrating it with the corresponding doctrine of partners in a coalition setting;
    - Keeping the required degrees of freedom open in doctrine, by:
        - being open enough to allow changes to itself, and
        - stimulating the consequently required adaptation of other properties.
    - making the organization reconfigurable so it can be adapted to the circumstances.
    - fostering an Adaptive Stance[15] at both the individual and the organizational scales through training and education.
    - educating leaders to facilitate and implement methods and techniques that stimulate diversity, learning and adaptivity, eg cultivating ambiguity tolerance, willingness to experiment and to accept some failures, brainstorming techniques, generating multi-dimensional feedback, and recording and dissemination it to others.
    - making individuals aware of their potential contribution to adaptation, encourging them to share their insights and to provide feedback, and training them to actively participate in teams that can operate in both competition and collaboration with other teams.

These examples are not intended to be exhaustive. Rather, they illustrate the breadth of the range of possible interventions and applications of adaptation and networks.

We close with some final pointers to open questions and further research that is needed.

Adaptivity does not come for free - there are costs involved in the Force Generation process, as well as opportunity costs in the force generated. So, the adaptivity 'control space' must be chosen and justified consciously. Different operations and operational phases may require different adaptivity levels and different adaptivity 'control spaces'. So, how do we quantify adaptivity for the force and for its sub-systems, including the three networks? How can the 'control space' be chosen deliberately?

[1] D.S. Alberts and R. E. Hayes *Planning: Complex Endeavors*, 2007 http://www.dodccrp.org/html4/books_main.html

[2] D.S. Alberts and R. E. Hayes *Poer to the Edge*, 2003 http://www.dodccrp.org/html4/books_main.html,

A.M. Grisogono, *The Implications of Complex Adaptive Systems Theory for Command and Control*, CCRTS, San Diego, June 2006.

[3] A.M. Grisogono, *Co-Adaptation*, invited paper 6039-1 Complex Systems Conference, SPIE International Symposium on Microelectronics MEMS and Nanotechnology, Conference 6039: Complex Systems. Brisbane, Dec 2005.

[4] P. Essens, M. Spaans, and W. Treurniet, *Agile Networking in Command and Control* C2 Journal, Vol 1, No 1, 2007

[5] M. Unewisse and A.M. Grisogono: A forthcoming paper will address the Force Development domain with an emphasis on how capability decisions can better enable flexibility for the subsequent domains.

[6] Grisogono, A.M., *Success and Failure in Adaptation*. Interjournal, 2006(1901).

[7] see 3 above

[8] see 4 above

[9] National Research Council, Committee on Network Science for Future Army Applications. 2006, Network science. Washington: The National Academies Press.

[10] M.Unewisse and A.M. Grisogono *Adaptivity-Led Networked Force Capability* 12th ICCRTS, Newport, 2007

[11] Initial conditions include the chemical state of the genome and the state of the physiological and biochemical environment in which it will develop.

[12] F.J. Odling-Smee, Laland, K.N. and M.W, Feldman, *Niche construction - the Nelected Process in Evolution* Princeton University Press, 2003

[13] M.W.Kirschner and J.C.Gerhart *The Plausibility of Life*, Yale University Press, 2005

[14] see 5 above

[15] A.M. Grisogono, *The Adaptive Stance*, www.complex07.org