The Variety Calculus – an alternative proposition for command & control in a complex world

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Abstract

Our hypothesis is that the contemporary approach to military operations is not adequately equipped to address the complexity of the modern operating environment. Complex situations are frequently not amenable to the reductive and deterministic thinking on which much current doctrine and methodology are based. Alternative ways of thinking about operations that factor in an understanding of the origins and implications of complexity are therefore required to facilitate the development of new approaches to Command & Control.

The "Variety Calculus" offers such a way of thinking that is a synthesis of concepts originating in Cybernetics and Complexity Science. We propose that the cybernetic concept of "requisite variety" offers an approach to facilitating self-awareness and situational awareness in order to gear the structure and processes of the operating enterprise to the nature of the operating environment.

We equate "variety" with the range of underlying relationships and interactions that combine to create the emergent properties of a complex operating situation. The Law of Requisite Variety implies that this variety must be matched by the operating enterprise to achieve effective understanding and action. This can be addressed by exploiting the recursive levels of organisation that exist in complex situations at different scales of observation to inform organisation and campaign design. It has implications for how internal relationships and activities are configured and conducted and begins to reveal a coherent approach to information, decision making, and the application of all levers of influence in order to deal with complex, emergent and volatile operating environments.

Introduction

The purpose of this work is to develop an alternative conceptual approach to military operations that would better inform campaign design and enterprise structure and processes in diverse and complex future operating environments. Its focus is on an alternative *way of thinking* that will support commanders' decision making and communication and can ultimately lead to the generation of novel practices that address some of the shortcomings identified in current approaches to Command and Control (C2)[1]. This paper describes a coherent series of concepts derived from Cybernetics (the science of control) and Complexity Theory and goes some way to indicating how they could be implemented in practice. It is not yet a fully-formed and tested solution, but rather a starting point for alternative thinking through which to constructively challenge conventional approaches and explore potential innovations through a wider conversation across the stakeholder community.

It is our hypothesis that the contemporary approach to the conduct of operations is not adequately equipped to address the *complexity* of the current or future operating environment. Complex problems and situations are not amenable to the reductive and deterministic thinking on which much current doctrine, methodology and ways of working are based. An understanding of the causes and implications of complexity can therefore inform the development of approaches to gear operating structures and processes to the nature of the operating environment, to generate both the situational awareness and self-awareness

[1] UK Ministry of Defence Development, Concepts and Doctrine Centre (2017) "Future of Command and Control", Joint Concept Note 2/17. https://www.gov.uk/government/publications/future-of-command-and-control-jcn-217

required to facilitate agility and adaptation, and to understand and exploit all possible levers of action in the effective delivery of operational goals.

The core concepts that underpin the current approach to operations arguably originated in less challenging times. This was the era of the Enlightenment and the Industrial Revolution when it was considered that the natural world and human organisations could be understood in deterministic terms. Like machines, their components were thought to interact in linear, additive ways to generate predictable outcomes, just as Newton's mathematics could predict the motion of the planets, or economic systems could be defined by Adam Smith's laws of supply and demand. Understanding could therefore be generated by reducing things to their component parts to identify the fundamental rules that governed their characteristics and behaviours and then reconstructing the whole from the sum of the parts. Such reductive approaches proved highly successful in addressing the *complicated* problems of the age, including those of military organisation and operation. The legacy of this thinking still exists in the modern military system, such as in the Military Appreciation and Estimate and the traditional chain of command.

In recent decades, it has been realised that the natural world and human systems are not *complicated*, but *complex*. They consist of multiple interrelated factors that combine to produce outcomes that could not have been predicted from reductive analysis and extrapolation of the resulting insights. This knowledge is quietly revolutionising our understanding of how we interact with each other and the wider world as well as the fundamental principles on which that world works, and it is precipitating profound changes in a wide range of disciplines, from economics to neuroscience[2,3].

The conduct of military operations has evolved incrementally over many decades in response to various societal, technological and military drivers. It could be argued that this has resulted in the development of larger, more complicated, less agile, and thus more vulnerable, headquarters (HQs) and systems of regulation and control. The pace of change has accelerated since the beginning of this century and advanced information capability is now available to the average citizen. Information is on a par with manoeuvre and firepower in determining military effectiveness and this places particular pressure on C2 with conventional military forces often disadvantaged compared to asymmetric adversaries that prove more agile and adaptable. Commercial corporations are rivalling nation states for power and influence, and the boundaries between military and non-military activities, peace and war, are becoming blurred. The operating environment is now considerably different from that in which the "Napoleonic System" and heroic models of leadership originated.

Opinions may differ on the status of military C2: whether or not it is fit for purpose in the current operating environment and whether or not it has the capacity for further incremental development to meet the demands of the future. Ultimately, if we come to a point where we cannot continue to rely on incremental change then we must re-think the underlying concepts on which our current approaches are based. According to the hypothesis expressed here, this means embracing complexity, rejecting the idea of simple cause-and-effect relationships, and developing alternative ways of achieving understanding, delivering influence and gaining decisive advantage.

[2] Waldrop MM (1994) "Complexity - the emerging science at the edge of order and chaos", Penguin Science
[3] Holland JH (2014) "Complexity - a very short introduction", Oxford University Press

Method & approach

This work began as an experiment to determine if an alternative conceptual approach to C2 could be devised that incorporated from the start the complexity of the modern operating environment. It brought together a Systems Thinking practitioner (GN) and a senior military expert (DC) in a series of meetings in which conventional approaches to military operations were discussed and challenged, and alternative ideas were explored. Systems Thinking offers an alternative to reductive mechanistic thinking in addressing complex problem situations. It includes a wide range of approaches and methodology, but tends to promote a holistic approach that focuses on the relationships between factors and multiple perspectives. It is particularly suitable for addressing issues that are complex, subjective, cross boundaries of organisation and discipline, or resist quantification and reductive analysis. It was intriguing to see if our different experiences and areas of expertise could combine productively to generate a coherent alternative view of military operations.

During an initial series of whole-day sessions, we identified key implications of complexity for the interactions between an operation and its operating environment, and we attempted to envisage from a fresh starting point what form appropriate responses to these factors may take. Hypotheses and underpinning theory were developed based on established concepts from Complexity Theory and Cybernetics and an outline of an alternative approach started to emerge. Our initial ideas were then refined through a programme of observations of military exercises, training events and planning activities, and conversations with serving military officers in all ranks and roles.

Testing and validating these ideas is not a trivial undertaking as it would be impractical to implement a new C2 paradigm in its entirety, or to judge its performance against conventional approaches in a scientifically robust controlled trial. Rather, we have sought in the first instance to describe an alternative *way of thinking* that can be adopted and tested by individuals for themselves to make their own judgements about its utility for the circumstances they find themselves in. We therefore present these ideas at a relatively early stage of development to enable us to engage more widely with the C2 community and to facilitate the widest possible exploration from different perspectives. We are also in the process of socialising this work with professionals involved in training, doctrine development and the conduct of operations with the intention of generating alternative methodology and developing opportunities for experimentation to transition from hypothesis to practice.

Military operations as complex systems

While there are numerous engineered systems of relevance to the military, such as platforms, weapon systems and information technology networks, we are focusing on the aspects that influence how the military think – how they analyse, plan, make decisions and organise. These are in the main *purposeful human systems.* The operating situation, for example, can be regarded as a system composed of the interactions between human actors and the environmental factors that influence their actions. The “operating enterprise”, the organisation that conducts the operation, is similarly composed of people and their interactions with each other and with the operating environment and adversary.

A “system” is defined here as a collection of items that are interrelated such that their properties and activities influence each other and the collective as a whole can be said to have characteristics and behaviours that distinguish it as a coherent entity within its environment. The act of differentiating a system from its environment implies an observer that can make such a distinction. Since no element of the human environment is truly isolated in a closed system, the placement of boundaries is a matter of *choice* and consequently dependent on the perspective of the observer. Thinking in terms of systems can therefore be regarded as a mechanism that helps us to observe and make sense of the mass of entities, activities and interactions that comprise our complex world. In a military context, we can regard as systems an operation, an operating situation, an adversary, a social grouping within an operation area, a military force element, an HQ, etc.

Complexity in systems arises from the property of “emergence”. This means that the system as a whole has characteristics and behaviours that are significantly different from those of its constituent components. These higher level properties do not simply represent the additive effects of the lower level properties but are a unique product of the interactions and relationships between system components. As an analogy, a diamond has properties such as hardness and lustre that cannot be ascribed to the individual carbon atoms of which it is composed. This cannot be ascribed solely to the aggregation of the properties of multiple carbon atoms since graphite (another form of carbon) differs from diamond. Rather, it is the nature of the *relationships* between atoms – the bonding and spatial configuration – that gives rise to the emergent higher level properties of the diamond.

Complex systems therefore have coherent higher level states that arise from the local relationships between their constituent components. These may be conceptual, such as the state of the economy, the mood of a nation, or the nature of a military situation. The relevant relationships that give rise to these states may take many different forms depending on the system in question, such as the forces between molecules in a material, or the financial transactions in an economy, or the interactions between people in a military headquarters. In each case, the perceived state or characteristics of the system represents the reconciliation of multiple underlying relationships with competing influences that give rise to a unique emergent outcome.

A second key feature of complex systems is that predictions about the emergent characteristics and behaviours of the system cannot be reliably made on the basis of knowledge of the properties of its constituent components in isolation. One implication of this is that complex systems are not amenable to the reductive or deterministic analyses that form many of our institutionalised approaches to objective problem solving or understanding, including military mission analysis and planning. This inherent uncertainty cannot be defeated by the pursuit of ever more detailed knowledge, which exacerbates the complexity. It cannot be *assumed* that specified actions in isolation will in combination deliver specific outcomes. In a complex operational situation, it cannot therefore be assumed that planned actions will result in the decisive conditions deemed necessary to meet operational goals or that these goals will in turn deliver the desired end-state. Simple linear relationships between localised actions and higher level outcomes, between cause and effect, break down in complex systems.

Variety and Requisite Variety

The concept of “variety” is well-established in the discipline of Cybernetics as being strongly related to both information and the idea of “control”[4,5]. It is central to the approach to military operations that will be outlined in this paper. For the purposes of this work, we consider variety as a factor that represents the diversity of lower level relationships that are involved

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[4] Ashby WR (1956) “An introduction to cybernetics”, reprinted 2015, Martino Books
[5] Beer S (1985) “Diagnosing the system for organisations”, Wiley

in generating the higher level emergent properties a system. For example, the variety of the human face includes all the factors that combine to make each unique, such as its size, shape, skin tone and the appearance and spatial relationships between the eyes, nose, mouth, ears, etc.

Variety can be directly related to other system characteristics that may help to place the concept in the context of military operations:

- The amount of *information* required to understand a system or situation
- The number of different *states* that a system has the potential to adopt
- The degree of *complexity* of a system.

Ashby's Law of Requisite Variety states that an effective controller must have variety greater than or equal to the system it seeks to control[4]. For example, if you wish to control a single stream of traffic, and you are concerned with only two states – moving and stationary – then a control system that also has two states is in theory sufficient to exert the required level of control. This condition would be met by a lamp that can be either on or off. In extrapolating this idea to a higher scale, a traffic control system is required to reconcile the conflicting demands of multiple streams of traffic on the basis of numerous different criteria such as vehicle types, destinations, direction of travel, environmental conditions, traffic density, etc. These represent the *variety* of the traffic system and the control mechanism thus needs a level of variety at least as great in order to be effective. This is addressed through lights, signage, lanes, road markings, priorities, rules, etc.

A military operation can be considered as a mechanism to exert control over an operating situation or adversary to achieve a specific purpose or outcome. Control of an HQ and the operating enterprise is also required in order to maintain their effectiveness in a dynamic situation and under external pressure. The principles of the Law of Requisite Variety are therefore relevant to operation, HQ and wider enterprise function and the ability to effectively deliver purposeful influence on the operating environment. We propose that requisite variety provides a lens through which to view the operation and its components *relative to the operating environment* that enables a condition for operational effectiveness to be met.

A particular challenge for military operations is to ensure that the operating structures and processes are effective under different circumstances and can adapt appropriately in a dynamic environment. This challenge is considerable in the absence of robust and timely methods to assess HQ and wider enterprise function, to understand the relevant environmental indicators that should inform ways of working, and the means to reconcile one with the other. Requisite variety appears to offer the potential for an approach to inform system diagnosis and campaign design, organisational design and mission planning.

Control of a complex system is likely to be elusive in terms of understanding and exploiting simple cause-and-effect relationships. This is probably not therefore the most appropriate word to describe one's relationship with a complex system and may also provide a misleading ethos for many military operations. A useful view is to consider a complex situation as a dynamic equilibrium where a particular balance between the competing underlying factors at any given time gives rise to a *relatively* stable emergent state. Changes in the higher level situation can be seen as "phase shifts" and "control" as the ability to influence the interplay of the lower order factors in order to achieve or maintain a desirable equilibrium state. Control is therefore less about the *imposition of will* on the operating environment or adversary, and more about steering the situation towards a desired equilibrium through the manipulation of the underlying balancing factors. Since this is a matter of *balance* it is reasonable that all the factors in play would have to be considered, as expressed by The Law of Requisite Variety. Failure to take a sufficiently holistic view of the operating situation in generating understanding and action can thus result in unintended consequences as actions on one aspect of the system result in unintended rebalancing effects elsewhere.

The Variety Calculus

It must be assumed that no single entity can have greater variety than the environment *of which it is a part*. There is therefore a "variety gap" between the operating enterprise and the operating environment that acts as a barrier to effective understanding and action. The operating enterprise can be seen as a mechanism for variety management to bridge the variety gap, establish requisite variety, and thus meet the conditions for effective understanding and influence. The operating enterprise therefore needs to:

- Amplify the variety available to the operation to observe and act on the environment
- Attenuate the environmental variety to enable the generation of understanding

This begins to provide insights into organisational and operation design and points the way towards design criteria to effectively gear the operation to the nature of the operating environment.

Every activity and relationship in the operating enterprise has inherent variety attenuating or amplifying characteristics that contribute to the net variety that can be brought to bear on the operating situation across the entire system. The term "Variety Calculus" captures the idea of managing competing variety attenuating and amplifying effects in order to attain a state of requisite variety with the operating environment. An appreciation of the influence of operation structures and activities on variety may thus provide a route to effective campaign and organisational design and function. For example:

- Training can increase variety if it provides new skills and abilities that address a wider range of potential circumstances; it can decrease variety by constraining people into a limited set of actions or responses. A similar analysis can be applied to doctrine and to the variety-reducing effects of defined processes and structures compared with more ad hoc ways of working.

- Collaboration increases the variety available to the operation as a whole by introducing the additional capabilities and perspectives other actors; it attenuates the variety of individual collaborators through the need to coordinate their actions to conform to a common effort.

- Communication increases the variety available to the recipient by offering information and perspectives not otherwise available. However, this is a variety-attenuated version of the sender's knowledge and understanding as it is constrained by the communication medium and their ability to articulate it. Variety amplification and attenuation therefore occur simultaneously from different perspectives. Consideration of the recipient's variety can inform the way that information is articulated and communicated.

- New technologies may increase variety by providing abilities not available to unaided humans; it may suppress variety by restricting the nature of inputs that can be accepted, processing algorithms, or the outputs that are generated. This can assist the assessment and configuration of new developments such as analytical tools and decision-making aids. It may provide insights into the configuration of autonomous systems and the impact of variety-attenuating controls and regulation.

- Subject matter experts and special advisors may increase variety by introducing alternative perspectives and options for action; they can suppress variety if their opinions are given disproportionate weight against other ideas.

The appropriate response to a situation can be seen in terms of a position on a variety spectrum. Certain indicators of the variety of the situation are suggestive of the type of response posture that would aim towards requisite variety (Figure 1). A low variety approach is more appropriate for relatively simple and predictable circumstances. This tends to suggest more defined and consistent response, such as may be the case with an emergency procedure. More complex and dynamic situations will require a high-variety approach that embraces multiple options and innovation. This could be viewed as achieving a balance between the needs for diversity versus uniformity, and between the use of tried and tested approaches versus innovation.

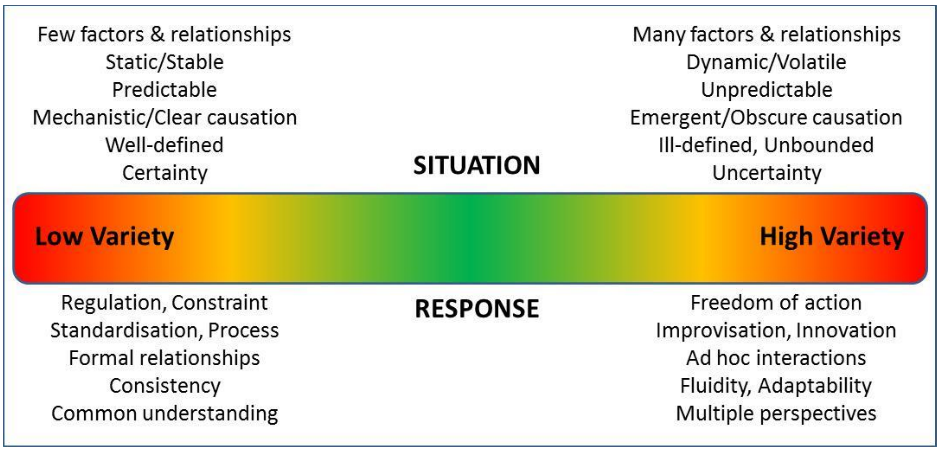

Figure 1 A qualitative indication of the appropriate posture required to achieve requisite variety

A situation is here presented as being positioned on a spectrum ranging from low variety to high variety. Representative indicators of possible characteristics of the positions left and right of arc are given by the upper descriptions. Similarly, the characteristics of possible low and high variety responses are indicated in the lower descriptions.

The variety of the operating enterprise can be amplified by enhancing the capabilities, relationships, range of outlooks, perspectives and experiences that are available to generate understanding and action. It could be argued that military organisations tend towards uniformity *in comparison with many of the operating environments they seek to influence*. This places organisations such as military HQs at a disadvantage in complex operations that have to take into account multiple facets and domains such as the social, political, economic and cyberspace aspects of diverse environments. There is perhaps a tacit acknowledgement of this manifest in the increase in specialist legal, policy, scientific and stabilisation advisors in HQs, in increased operation in coalition with allies and partners, and recognition of the need for a comprehensive approach that exploits all levers of influence. In general terms, it is advantageous to the function of an individual HQ to increase the perspectives and interpretations that are applied to information gathering and interpretation, and to explore more diverse options in planning. Processes that enable a more holistic and inclusive approach and avoid group think or rushing to consensus would also be beneficial. This is illustrated in Figure 2, which provides an example of the implications of the Variety Calculus principles in the context of understanding and planning.

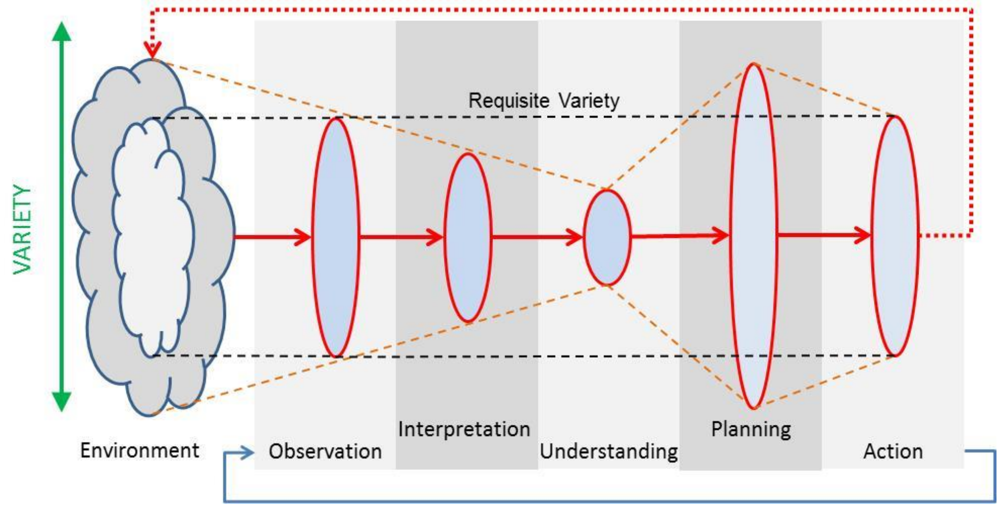

Figure 2 A graphical representation of the variety considerations during a planning cycle.

The amount of variety is represented by the relative size of each object, with the different components of variety equating to the stages of the process. The environmental variety is reduced by consideration of purpose and context and by selection of the appropriate scale of observation, as represented by the smaller inner cloud (see later text for further discussion). The conditions for effective operation are illustrated by the horizontal line of "requisite variety" that shows equivalence between the environmental variety and that brought to bear in observation and action. As only variety can see variety, the environmental variety detected is predicated on the variety of observation. Maximising this requires multiple types and sources of information. The generation of understanding is an inherently variety-attenuating activity since it reduces the number of possible interpretations of the available information. Taking action also reduces variety as it involves selecting a sub-set of all possible actions. This highlights that the attainment of requisite variety is dependent on divergent thinking during the generation of understanding, and consideration of multiple options during planning.

Attenuation of environmental variety to facilitate understanding is an equally important aspect of the Variety Calculus, but it presents a greater challenge. This means creating a view that facilitates understanding, not destroying the actual factors and relationships that compose the environment. In attenuating variety, we are therefore making decisions about how to view the environment and to process those observations. The perception of the emergent state of the environment is to a large extent a subjective judgement based on the purpose and context of the observer. This means that elements of the absolute environmental variety vary in their influence on the perceived emergent situation. A clear articulation of purpose and context (for example through the Commander's Intent or Operation Directive) thus provides a basis for environmental variety attenuation. For example, in the traffic management analogy described earlier, the *absolute* variety of the traffic system could include factors such as the colours of the vehicles. However, when viewed in the context of controlling traffic flow, this would not influence the emergent state and could therefore be excluded from the *relevant* variety. By defining variety in terms of the factors that create the subjective emergent state, we enable context and purpose to be used as variety attenuators that provide boundaries for the identification of environmental variety.

A further consideration for variety attenuation is operation tempo. When there is a clear imperative for immediate action then it could be argued that certain overriding factors become preeminent in defining the environmental state, and that their impact is to limit the range of actions required by the operation in response. For example, a warship is a complex entity with multiple factors to be considered in its effective operation. If there is a fire on board, the rate at which it is impacting on the ship's function or integrity has a bearing on its importance as a factor, to the extent that it may be the only factor to be considered if the vessel is seriously endangered. This represents an effective attenuation of the relevant environmental variety and shifts the appropriate posture towards a low-variety response (to fight the fire or abandon ship). Although our thinking on this is at an early stage, this idea suggests that there is a mutual dependency between tempo and variety that invites consideration of the idea of "Requisite Tempo". This may be a useful lens through which to define and assess operational tempo relative to the environment. Furthermore, in keeping with the idea of a dynamic equilibrium, the tempo of change tends to be greater at lower levels of a system. This consideration could inform the gearing of battle rhythms of different elements of the operating enterprise.

The scale at which a situation or system is observed is an important contributor to the variety that is perceived by the observer. A high level view presents less detail and information and is therefore low variety compared to a highly detailed low level view. As illustrated in Figure 3, this implies that the perceived variety, and hence the complexity of a situation, can be better managed through the selection of an appropriate scale of observation. This is a key element of the Variety Calculus that impacts on system design and operation and the relationships between actors at different positions in the system.

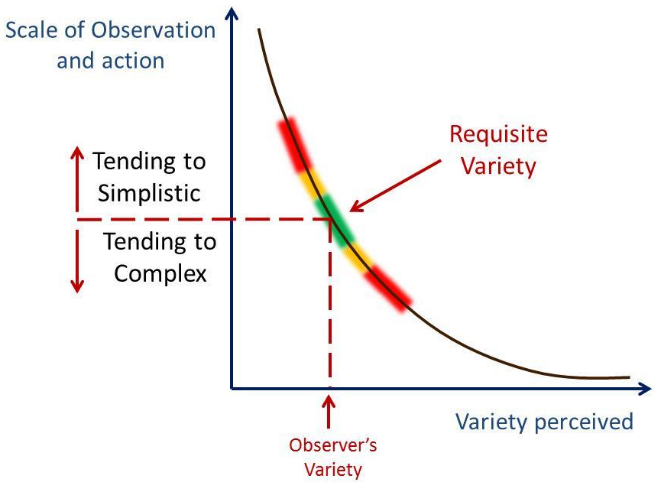

Figure 3 The relationship between the scale at which a system is observed and the perceived variety.

The ability to understand the observed system is optimised at the position of requisite variety where the observer's variety is equivalent to the perceived variety. If observed at a scale which is too low (too much detail), then the system is perceived as complex. If the system is observed at a scale that is too high then the resulting understanding may be too simplistic and of low utility.

Designing for complexity

In practice, complex systems can comprise multiple levels of organisation at different scales of observation. For example, if an individual person is considered as a system, then at a lower scale of observation you may see organs and tissues that are composed of cells, which are in turn formed from cell components. At lower still, these resolve into molecules and atoms. If you observed at a higher scale then you may see families, communities, and societies. Each of these can be recognised as independent and coherent entities with different characteristics and properties that exist at different scales of observation. Complex systems thus have recursive hierarchical structures in which the emergent states of the higher levels are the product of the relationships and interactions within the levels below. We refer to these different levels of structure in this text as "Levels of Recursion" (LoR).

Bar-Yam previously considered the Law of Requisite Variety with respect to system structure and the role of different scales of observation and action. This identified limitations inherent in conventional hierarchical and centralised control models[6]. The perceived variety is higher when lower LoRs of a system are observed. An actor therefore requires greater variety to achieve effective understanding and action when operating with respect to lower LoRs compared to higher LoRs. There is also a necessary play off between scale and scope. Since an individual observer has limited personal variety they may be unable to generate a full understanding of a whole system at a low LoR. This begins to form an explanation in variety terms of the inherent uncertainty in complex systems whereby emergent properties cannot easily be reconciled with lower level observations. There are effectively variety gaps between different LoRs that act as barriers to effective understanding and action. This is significant for the design of military operations which are generally conceived at a high LoR (e.g. the strategic or political level) and yet the individual actions taken to influence the situation mainly occur at a low LoR (e.g. tactical). This variety gap is a central challenge to the generation and function of a coherent purposeful operating enterprise.

People construct hierarchical organisations to enact complex activities in all areas of human endeavour. Although they are not considered overtly in these terms, such organisations function as variety management mechanisms that bridge the variety gaps between their strategic purpose and their tactical actions, and between themselves and the environment in which they operate. They achieve this by offering a stepwise transition between domains of different variety, thus reducing the size of each variety gap that must be bridged. Their pyramidal structures enable amplification of the variety of observation and action available to the enterprise and attenuation of variety of information up through the system to manage the generation of understanding. They reconcile scale and scope by having more actors at the lower levels than the higher.

We propose that it may be possible to optimise the function of a military operation and gear it specifically to the nature of the environment by designing and operating it overtly as a mechanism to manage the described variety gaps. This can be achieved by building a recursive hierarchical enterprise where the levels match the LoRs perceived in the operating environment such that each level can achieve requisite variety. This hypothetically ideal system would be designed incrementally from the top down with each LoR establishing its own relationship with its operating environment and designing and commissioning the level below according to the identified need for variety amplification. This will optimise the ability to understand, plan and act at each level and thus manage the overall complexity of the

[6] Bar-Yam Y (2004) "Multiscale variety in complex systems" Complexity 9: 37-45

operating situation. Such a system could be said to be configured for complexity. This principle is illustrated in Figure 4.

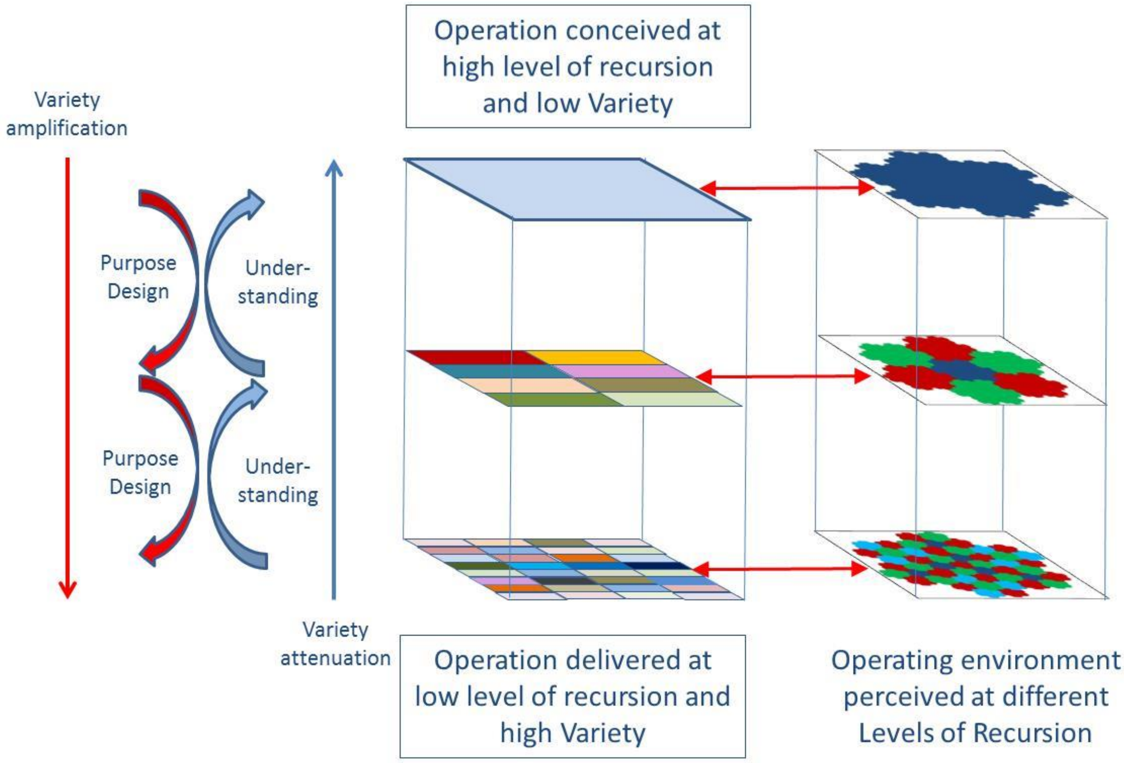

Figure 4 An illustration of the use of a recursive system structure to manage enterprise variety and maximise the potential for understanding at each level

Different Levels of Recursion of the operating environment can be observed that present different amounts of variety to the observer. These are presented on the right with the variety represented by the number of coloured shapes. The operating enterprise (central column) is designed to match the variety of the operating environment by being composed of equivalent recursive levels that offer corresponding variety. Each organisational LoR is thus well configured to understand and gain purposeful influence when operating with respect to its appropriate environmental scale and scope. The multiple levels of the enterprise enable the effective transmission of information and understanding up through the system by providing intermediate levels that reduce the variety gaps that must be transitioned in each case. Communication across variety gaps thus becomes more manageable. Similarly, they facilitate the effective dissemination of purpose and context throughout the system and amplify the variety that the enterprise can bring to bear on the operating situation. Since each level is operating under conditions of requisite variety with its observed environment, and is managing variety in its internal relationships between levels, then the entire enterprise as a whole is configured as a unified and coherent entity that can address the complexity of the operating environment. As this must be achieved without exceeding the information capacity or the variety of an individual component of the system, more actors are required at lower levels, each of which has a more detailed view of a smaller portion of the overall operating situation, thus balancing scale and scope. The recursive system is built successively as understanding is generated at the higher levels, thus giving rise to a bespoke operating enterprise, geared to the complexity of the situation.

Military operations conventionally incorporate hierarchical recursive organisational structures. We see this in the design of force elements, the distinctions made between strategic, operational and tactical levels of command, and in the formulation of policy, strategy, plans and action. At present, the recursive structures are well-developed but are not explicitly configured to optimise the ability to develop understanding and carry out effective purposeful action according to the concepts described here. They also tend to be fixed rather than designed specifically for the nature of the operation and operating environment. The concepts described here provide a basis for the design of bespoke operating structures that are self-organising and employ hierarchy only to the extent required to manage complexity under the prevailing circumstances. Potential benefits of such a system could be improved generation of understanding at each level, clear distinctions between the remits and spheres of influence of each tier of the hierarchy as defined by their respective LoRs, and greater efficiency where the number of hierarchical levels can be reduced.

Maintaining operation coherence

Due to the inherent barriers to understanding and effective influence that exist across LoRs of differing variety, higher level actors must have confidence and trust in subordinates making decisions about how best to exploit their more detailed understanding of the situation and to thus maximise the variety they contribute. This must be balanced with the need for higher level actors to coordinate and de-conflict subordinate activities, distribute shared resources, and to integrate partners and allies – activities that are inherently variety attenuating and also require a wider overview not available at the lower level. In addition, the integrity of the high level purpose of the operation must be maintained in the context of a self-organising enterprise that embraces and exploits individual perspectives at multiple levels of organisation. This is about the disbursement of purpose, understanding and intent, the relationships between higher level objectives and lower level actions, and the generation of Joint Action and Effect.

It cannot be taken for granted that there will be a common understanding of the situation, or of operational purpose, between actors at different LoRs. Each effectively exists in a different environment with different characteristics and different relationships between the entities they perceive. This idea has a precedent in the concept of Distributed Situation Awareness that originated in Ergonomics[7]. This states that actors in a systems do not share a common situational awareness, but that awareness is distributed across multiple agents with different viewpoints and perspectives. Full situational awareness is thus a function of those of the separate agents and the relationships between them. We would thus say that it is an emergent property of the system applicable to the enterprise as a whole.

Furthermore, the enterprise could be said to consist of multiple such distributed factors that define its higher level character. These include:

- Purpose or Goals
- Information/Understanding
- Actions
- Tempo

Each agent in the system thus has its own values that can be attributed to these elements that are unique to their position in the enterprise and their perspective on the environment. Characteristics of the enterprise as a whole, such as effectiveness, efficiency and coherency, are functions of the relationships between agents within the system with respect to these factors. They therefore represent different system "dimensions" that can be used as a framework for considering system emergent properties.

[7] Stanton NA et al (2006) "Distributed situation awareness in dynamic systems: theoretical development and application of an ergonomic methodology" Ergonomics 49: 1288-1311.

Our view of the operating enterprise as a complex system places the emphasis on the nature of individual localised relationships between system actors in generating the emergent properties of the operation as purposeful and coherent. Such relationships involve bridging variety gaps and reconciling *different but valid* perspectives in order to maximise the benefits that these bring and to find appropriate balances in the Variety Calculus between freedom of action and regulation. This cannot be achieved through a top-down directive chain-of-command, but through dialogues and exchange of narratives that lead to a better understanding between partner actors. The aim is not necessarily to establish a common truth, which may well be elusive in a complex environment, but to ensure that a rich and more holistic appreciation is factored into decision making, and to harness and manage the localised relationships from which the emergent properties of the system are built. The concepts of variety, requisite variety and LoRs help to provide a language to enable the necessary dialogues throughout the system.

The perspective of each actor will be conditioned by their unique viewpoint and the LoR at which they operate, and also by their nature, experience and worldview. This consideration is becoming increasingly important when one considers integrated operations that include non-military actors. In order to avoid invalid assumptions, each relationship should be negotiated on a case-by-case basis and re-evaluated during the progress of the operation through on-going dialogue. The Variety Calculus emphasises the need for such an approach with all relationships, rather than fixed assumptions about the nature of relationships between military actors.

The concept of variety can assist in framing communications, and hence the transmission of purpose and understanding, across LoR boundaries. If a recipient is to maximise their understanding then they must maintain requisite variety with the communications they receive. Each will receive information from multiple senders and the totality of the variety of communications they receive should not exceed their own variety. Variety attenuation is therefore essential for effective information fusion and transmission. While variety attenuation is an inevitable consequence of communication, an understanding of this and of the perspective of the recipient can help to frame communications appropriately.

Information can be viewed in a number or ways that differ in the variety they present. For example, the variety of data > information > knowledge > understanding. This implies that the transmission of understanding rather than data may result in more effective communication to a recipient operating at a lower variety level. This also has implications for the idea of universal availability of information which places a large variety management burden on the exploitation of that information. Each user would have to reconcile the available data to their own LoR of interest and achieve considerable variety attenuation. Rather, it may be more efficient and effective to manage communication flows and information disbursement such that each transmission is configured appropriately to the variety gap that it must bridge and the LoR of the recipient.

The recursive nature of this operating model may appear similar to the type of hierarchies that are used currently by the military, but the resemblance is superficial. This approach envisages a recursive system that is quite different from a conventional chain of command. The different tiers are products of the respective environmental LoRs that each is working to, not of the authorities or ranks of the actors involved. It is not a hierarchy in the sense that higher tiers have *dominance* over lower tiers and seek to dictate their activities. It is hierarchical only in the sense that it has a recursive organisational structure used to establish and manage different levels of understanding of the operating situation. The lower tiers should not be considered as extensions of the eyes and hands of the higher tiers, but rather the whole should be considered as an integrated entity where all elements are supported by, and supportive of, their connected neighbours. This presents an "enterprise approach" to operations rather than a "chain of command".

Each level endeavours to understand the requirements of the level above for understanding and action, and to set the conditions required to enable the level below to effectively engage with its situation. Variety and requisite variety provide concepts that can help the development of effective relationships by supporting the framing of intent and purpose and the fusion and translation of information between levels. This therefore becomes a key medium to achieve operating continuity and coherence. A schematic overview of this approach to operations is shown in Figure 5. The Variety Calculus thus provides model that can shape operational design and a proposition to enable the implications of operational complexity to be addressed.

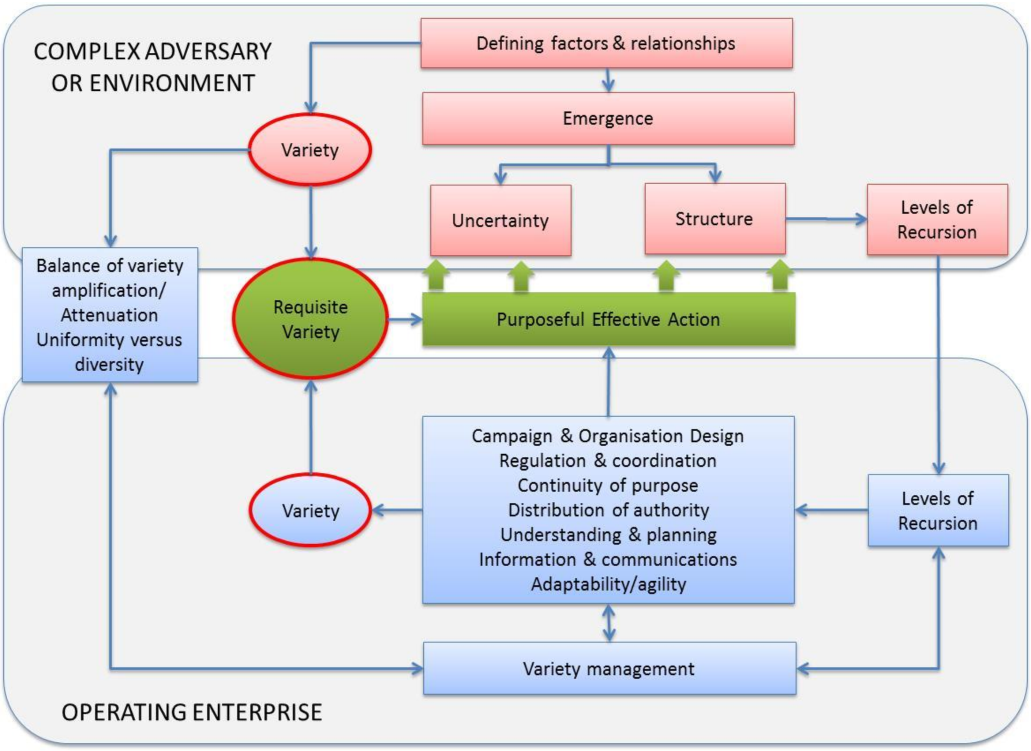

Figure 5 A summary of the approach to military operations outlined in this paper

The variety inherent in the operating environment is defined by the factors and relationships that give rise to its emergent state. Emergence results in both the uncertainty in the future state of the situation or its response to stimulus, and the recursive structures that can be exploited to facilitate understanding. Effective purposeful action by the operating enterprise is enabled by ensuring that it can bring requisite variety to bear through a process of variety management. This is achieved through balancing the variety attenuation and amplification effects in organisation, campaign and process design, and by exploiting the levels of recursion inherent in the situation to build an operating enterprise that is configured for the complexity of the environment.

From hypothesis to application

At the present time, the ideas expressed in this paper represent a hypothesis and are designed to serve as a basis for wider discussion and debate that can lead to improved practice in the conduct of operations. It is not feasible to implement these ideas *in their entirety* in a robust controlled experiment that can test them against conventional practice. It is therefore desirable to explore potential ways of implementing the *principles* of the Variety Calculus such that they can be experienced by military officers in an appropriate environment and to move towards influencing the development of a body of practice. To this end, work is in progress to establish routes for experimentation with the UK military.

In the first instance, we are focusing on two aspects of the Variety Calculus as vehicles for experimentation and the development of methodology. These are the related areas of facilitating constructive dialogue between actors and an alternative planning process. We see both of these as being founded on the construction of "purposeful narratives" that articulate an understanding of the operating situation and the appropriate operational response. The view of operations presented here makes dialogue between directly connected actors preeminent in the maintenance of system coherency through the distribution of purpose, exchange of understandings, and reconciliation of conflicting requirements. This directly feeds into decision making about the actions taken to deliver the operation purpose.

This element of the work was developed through the observation of military exercises and training activities. We found that during this process our ideas started to converge with some of the key elements of the Systems Thinking approach of Soft Systems Methodology (SSM)[8]. We developed a framework consisting of seven elements that can be used to exploit an understanding of the operating situation and to construct a purposeful narrative that articulates that understanding:

Purpose: This forms the foundation of the narrative and drives other considerations. It will be derived in the first instance from the communication received from the higher tier of the operating enterprise, but framed in the context that is relevant to the current LoR. It identifies the reason for the operational activity to be undertaken rather than what will be done and how it will be achieved. The key verb phrase should provide a reflection of intent and agency, with modifiers or qualifiers used to ensure that the scope of the purpose is appropriately bounded.

Policies & Constraints: Policies represent the decisions already made at a higher level of the operating enterprise that will influence how the planners view and respond to their situation (e.g. Rules of Engagement, or defined strategy). It is necessary to acknowledge these to maintain operation coherence and to inform future options and actions. These reduce the variety available to a lower tier as they limit the scope of potential activity, but they are often necessary to coordinate or deconflict actions and distribute shared resources. Constraints represent limitations that the system has no control over, such as weather, terrain or equipment limitations.

Perspectives: This introduces other actors or constituencies that are relevant to the operating situation and may thus shape the decisions made about how to pursue the Purpose. They represent the views of independent agencies whose opinions or actions are relevant to the Purpose to be achieved, or are intended to be influenced by actions taken.

[8] Checkland P (1999) "Systems thinking, systems practice", Wiley

This could include an adversary, a local population, an individual, the population at home, a commander, subordinate force elements, etc. It may include key decision-making authorities, or agents who will enact activities. Their influence on decision making should be expressed. This is one means of identifying and incorporating the variety within the operating environment into narrative development.

Partnerships: This also concerns other actors in the operating environment, but in this case acknowledges where the actions of others can be coordinated with your own for operational advantage. It may be that partnerships are essential for operational delivery, or that they are elective. The degree of agency or influence should be taken into account. This will influence how Purpose can be delivered and help to identify those organisations that it is necessary to establish relationships with and the potential nature of these relationships.

Pace: This factors time and the need for requisite tempo into the narrative and recognises any requirement for explicit time limits or deadlines, where activities must be phased with other tasks, or the intervals for assessment and revision of the plan. It will be necessary to ensure that the tempo of the operational activity takes into account the pace of change in the environment, and that battle rhythm cycles are appropriately synchronised between different LoRs of the operating enterprise. In many instances, the time window for action will dictate how planning is approached and the number of factors that can be considered. This is directly linked to the risk inherent in the situation – the risk of doing the wrong thing versus the risk of acting too slowly.

Prerequisites: It is likely that not all the information required to understand a situation and to provide the required context is available. Also, decisions by others that are necessary to inform subsequent actions may not have been taken. Prerequisites provide a means of acknowledging where such gaps exist. This may inform the Commander's Critical Information Requirements or Requests for Information.

Posture: Consideration of the above factors is intended to generate a holistic and concise narrative to inform the purpose and context of the operation or other operational tasks with a view to managing variety. This in turn informs the decisions required about the types of activities necessary to deliver the Purpose under the circumstances described. Posture thus describes these activities.

HQ staff must first gather and analyse the required information relating to the operating situation in order to understand the relevant variety that they must address. This requires a holistic view of the operating environment and must focus on the relationships and interdependencies between factors in order to gain an appreciation of the key drivers that give rise to its emergent state. These explorations should focus clearly on the relevant LoR as this is critical to effective understanding and to the role of the HQ and its integration into the wider enterprise. The demands of requisite variety imply that diverse sources of information and perspectives should be exploited to enrich the understanding that is developed.

Planners can then address the implications of their understanding for the further prosecution of the operation by considering each of the elements of the above framework. This must also be targeted specifically to the relevant environmental LoR with which they are concerned, and should take into account the consideration of variety in developing their responses. These responses can then be combined into a narrative text that provides a clear expression of their perspective. The framework is intended to be a vehicle for challenge and the testing of multiple views and interpretations. Its use should therefore foster dialogue and debate within the HQ that enhances the variety that is brought to bear in interpreting and exploiting situational understanding. Developing understanding and associated narratives will be a cyclic iterative process that continues throughout the operation.

The resulting narrative can then be used in two ways. Firstly, it can be used as a basis for a dialogue with subordinates and partners in an exchange of narratives. It effectively provides purpose and context that can form the basis of commander's intent, not necessary as a definitive directive but as a starting point for the conversation about specific actions to be taken and the needs for regulation.

Secondly it can form the basis for further planning activities and the identification of the type of elements that should be commissioned to operate at a lower LoR. In following the same ethos as SSM, and consistent with Variety Calculus principles, this would see the plan as having a recursive structure that transitions from a low variety starting point offering low detail through a iterative process to the required higher variety position. This is a variety amplifying transition to inform the design of the lower level of the enterprise. To achieve this, the purposeful narrative is used to identify specific activities within the text that are required to deliver the stated purpose. These then form the basis for Purpose statements in their own right. The framework is then applied to these sub-activities to generate subsequent narratives and more detailed activity generation. Importantly, as each iteration of task generation is completed, a model can be built that identifies the relationships and interdependencies between the tasks. This serves as a means of testing the coherency of the developing plan, and also ensures a focus on the important relationships between plan elements. This approach is currently being tested in a variety of contexts, including in non-military activities.

Conclusions

In recognising complexity as a core issue at the heart of the challenges facing military commanders, it becomes clear that the operating situation, an adversary, operating enterprise and an HQ could all be regarded as complex systems. Combining this with the cybernetic concept of requisite variety as a precondition of "control", or effective purposeful influence, provides the means to consider the conduct of operations in a novel and constructively critical process. The Variety Calculus concepts are in principle universal and unifying: applicable to all operation levels from tactical to grand strategic, and to situations ranging from the complex to the relatively simple. They can be potentially applied to all aspects of the operational art since all have variety components that contribute to the emergent characteristics of the operation. They are also scalable and can be applied to the design and function of a team, an HQ or the operating enterprise.

Consideration of complexity shifts thinking away from mechanistic approaches, predefined operating structures, and fixed assumptions about the relationships between system components and between actions and effects. Rather, operating structures can be designed according to the needs of the operation, configured for complexity and geared to bridge the variety gap between the high level operation purpose and its lowest level execution. This uses LoRs to orientate an observer within a complex system, to establish a consistent basis for understanding, planning and action, and to configure the relationships between different components of the operating enterprise. This relies on dialogue between actors based around purposeful narratives to maintain system coherency and integrity of purpose by establishing appropriate relationships that reconcile different operational perspectives and help to balance conflicting needs of regulation and freedom of action. The Variety Calculus provides language and metaphor to support such dialogue.

We view variety as a driver of competitive adaptation and agility and a practical yardstick for assessing the potential of the system to respond to dynamic and uncertain operational environments. It offers a lens that can facilitate the generation of self-awareness and situational awareness and how the two can be compared to inform operational design and assessment. The Variety Calculus integrates the concepts of requisite variety, requisite tempo, LoRs and variety gaps to provide a theoretical underpinning that may validate and point a way towards the delivery of key aspirations for operations in the face of complexity. This includes the exploitation of all levers of influence in a "Fusion Doctrine", the gathering, processing and disbursement of information in achieving "Information Advantage", and the orchestration of military effects through integrated and coherent organisational design and regulation. It is a recipe for competitive advantage in a complex world.

There are several ways in which this approach to the conduct of military operations presents an alternative to the current paradigm or other emerging concepts.

- It suggests that hierarchy is a positive characteristic of the organisational structures *if appropriately designed and exploited to address complexity*. Much current thinking favours flat structures to achieve improved information availability and freedom of manoeuvre[9].
- Some current thinking favours universal availability of information in the pursuit of common understanding[10]. The proposed approach acknowledges the existence of different information domains within the recursive structure of a complex operating enterprise and the need for careful calibration of information flows in order to maintain requisite variety. It casts some doubt on the validity of the concept of a genuinely common understanding at all points in a complex system. Rather, it prioritises a common understanding of *purpose* within local relationships.
- It suggests that the form of the operating enterprise should be allowed to emerge through the application of relatively simple principles that govern the relationships between individual actors and thus form the relationship between the operation and the operating situation. This contrasts with both fixed operating structures regardless of the situation, and a "playbook" of different approaches for use for predefined operation types.
- While *authority* can be exerted across LoR boundaries, the ideas presented on variety suggest that this is not the case for *effective control*. This approach therefore takes the emphasis away from "command and control" dominance of a higher level over a lower level towards an enterprise approach to operations. Although this does not challenge the concept of Commander's Intent in current practice, it may provide Commanders with a clearer framework for its development and a test to provide assurance that their mission narrative is appropriately articulated.

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[9] See for example the "Power to the Edge" C2 approach described in NATO RTO Technical Report AC/323(SAS-050)TP/50. This contrasts fully distributed patterns of interaction with the conventional hierarchical approach.
[10] See for example: McChrystal S, Silverman D, Collins T (2015) "Team of Teams. New rules of engagement for a complex world", Penguin

These ideas are presented at an early stage of development as a hypothesis and a proposition. That proposition must now be tested. To this end, work is in progress to develop approaches to its practical application and to engage with the communities involved in research, training, doctrine development and practice to generate opportunities for experimentation. It is our philosophy to address the challenges presented by the implementation of novel approaches to military operations by integrating the perspectives of expert communities into the development process. Readers are therefore invited to explore these ideas and contribute their thoughts, comments and challenges as we work towards meeting the aspirations for future C2.