Implications of the Complex Adaptive Systems Paradigm

PWGSC Contract Number: W7714-156105/001/SV TASK 006
ISR Report 6070-01-02
Version 3.0
9 March 2017

DRDC-RDDC-2017-C052

Presented to:

Dr. Peter Dobias and Cheryl Eisler
MARPAC Operational Research Team,
Defence Research and Development Canada – Centre for Operational Research and Analysis
PO Box 1700 STN Forces
Victoria, BC V9A 7N2

Prepared by:

International Safety Research
38 Colonnade Road North
Ottawa, Ontario
Canada K2E 7J6

Abstract

Complex Adaptive Systems (CAS) theory is a framework which emerged in the late 1990s to describe, model, study and analyze systems that contain many diverse parts that are interconnected, act independently, self-organize and are non-linear. Over the last twenty years CAS theory has undergone refinement and has been applied in the military context, to assist militaries in adapting to the increasingly rapid pace of change in the security environment.

This report examines the implications of the CAS paradigm for the Royal Canadian Navy. Building on the *Adaptive Fleet Literature Review* completed in January 2017, and viewing the Future Security Environment through the lens of CAS, it assesses how the CAS framework could be applied to assist in planning the future fleet.

The CAS framework is not a bold alteration of course. It is a subtle but important change in approach which could complement Capability Based Planning and the most recent *Fleet Mix Study Iteration II*. By focusing on adaptability and complexity as beneficial characteristics of a force, the CAS framework has the potential to assist in informing RCN force development decisions; enhance the generation of the force; and help to deliver a future force more apt to deal with the vagaries of a complex, unpredictable and changing world.

The approach this report takes is to provide a broad survey to raise issues for further consideration, and does not go into great detail. It does, however indicate where further examination is likely to be useful, and underscores that a level of effort would be required to develop the tools to support CAS modelling in the RCN context. The report excludes discussion of Command and Control in any detail, but recognizes that this is an area where CAS theory could have significant impact.

Author Biography

This paper was prepared by Peter Ellis, a retired Canadian Rear-Admiral with an extensive background in joint and maritime operations, force generation and force development. He served four years as Deputy-Commander of the Canadian Joint Operations Command. His naval experience includes service in submarines and appointments as Commanding Officer of HMCS Halifax; Commandant of the Naval Operations School; Amphibious Task Group Commander for the Standing Contingency Force (2006); Deputy Commander and Commander of the Pacific Fleet; and Commander of Task Force 176, the Expeditionary (amphibious) Strike Force during RIMPAC 2012. He also completed tours as Director of Maritime Requirements (Sea), and Director-General, Maritime Force Development.

QUALITY ASSURANCE AND VERSION TRACKING

Authorization

Title	**Implications of the Complex Adaptive Systems Paradigm**	
Report number	6070-01-02	
Version	3.0	Signature
Prepared by	Peter Ellis	
Reviewed by	Devin Duncan	
Approved by	Devin Duncan	
Approved for Corporate Release by	Mike McCall	

Version Tracking

Ver.	Action	By	Date
1.0	Release to client	Mike McCall	18 Feb 17
2.0	Release to client	Mike McCall	2 Mar 17
3.0	Release to client	Mike McCall	9 Mar 17

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1. INTRODUCTION

"Adaptation is an imperative for the Joint Force. The character of war in the 21st century has changed, and if we fail to keep pace with the speed of war, we will lose the ability to compete. The Joint Force is full of the most talented men and women in the world, and it is our responsibility as leaders to unleash their initiative to adapt and innovate to meet tomorrow's challenges. We will get no credit tomorrow for what we did yesterday."

-General Joseph F. Dunford, Jr.
Chairman of the Joint Chiefs of Staff [1:3]

1.1 Aim and scope

This paper is a part of an effort to develop a force structure and concept development paradigm for the RCN based on the Complex Adaptive Systems (CAS) approach. [2:1] It assesses how the CAS paradigm (as documented in the "Adaptive Fleet Literature Review" [3]) could be used to improve future fleet planning and analysis.

The assessment will be nested in the context of the Future Security Environment and Force Planning, with specific reference to force planning documents provided by the Technical Authority. It offers comments on whether and where the CAS paradigm (primarily focussed on adaptability) may be useful to inform and support the Navy's force development effort. It identifies issues and questions for further investigation; however, detailed analysis of options is beyond the scope of this task.

The approach taken is to review the work done in *Adaptive Fleet Literature Review* 3 and summarize the framework which CAS theory provides. It then describes how the RCN fits into the CAS framework and proceeds with a discussion of the application of the CAS paradigm to the future RCN, (Identification of the "so what" of CAS) in the areas of:

a. Future operating environment.
b. Force structure.
c. Force generation.
d. Modelling and simulation.

While detailed discussion of Command and Control is beyond the scope of this analysis, this paper will (necessarily) touch on some aspects of the Command and Control of maritime operations.

1.2 CAS Framework

Complex Adaptive Systems theory has developed over the past twenty-five years [3:1] to provide a framework within which to describe and model systems which, put simply, “are systems that have a large numbers [sic] of components, often called agents, that interact and adapt or learn.” [4:1]

In assessing the applicability of the CAS paradigm, it is important to review what qualities make a system complex and adaptive. Given that CAS theory is still in development, and different experts use differing terminology and approaches to describe the CAS paradigm, it is important to bring focus to its key characteristics. CAS are systems which are marked by complexity, adaptability, and interdependence. They act in non-linear ways and are self-organizing.

1.2.1 Complexity

A system exhibits complexity when it is made up of a large number of individual components called agents. These agents can sense and act independently. A greater number of agents add to a CAS’ complexity.

Those agents should be diverse, in the sense that their behaviours or functions are different from one another. The more diverse the agents, the greater the complexity of the system is.

The CAS’ diverse agents must be interconnected, permitting them to interact and contribute to, or influence and shape the system’s behaviour. The more they are interconnected, the greater the complexity.

Diverse agents are frequently organized into sub-systems that are also inter-connected. In many hierarchical structures, these sub-systems can be described as existing at differing scales, from fine to large-scale. The term system-of-systems is often used to describe CAS.

One of the foremost researchers in the area of CAS and its applications to the military, Yaneer Bar-Yam, offers that complexity is a quality which militaries should seek as it enhances their abilities to deal with complex problems, and do so more rapidly and effectively than in using hierarchical decision-making processes. [3:19]

1.2.2 Adaptability

CAS systems adapt to their environment. They “change their behavior to improve their chances of survival or success—through learning or evolutionary processes.” [5:13]

Evolution implies a longer-term refinement of desirable characteristics (selection) which have proved to be more beneficial to the system over time. Adding the Sea King helicopters to the St-Laurent class destroyers is an example of evolution.

Learning is a short term process which is the ability to apply past experience and knowledge to future events. Opting to deploy a “Gulf-mod” Sea King to a humanitarian mission is an example of learning.

In the context of a military force, three different qualities are useful to describe a CAS' ability to adapt in response to and under conditions of stress:

a. Robustness is the ability of a system to withstand the effects of force. Its capabilities, redundancies and re-configurability contribute to robustness;
b. Resilience is the ability to recover capability following an initial degradation of a force placed under stress; and
c. Anti-Fragility is the ability for a system to gain strength while exposed to stresses such as force. This implies that the stressed system must be dynamic in its reactions to stress in order to grow stronger during the conflict [6:13].

1.2.3 Interdependence

The agents in a CAS are interdependent. Although they act independently, their actions are shaped by external stimuli and by their interactions with the system. As summarized by Eric Beinhocker of the University of Oxford: "What you do depends on what you expect me to do, which in turn depends on what I expect you to do, and so on." [5:12]

In a military context, this interdependence can be related to diversity, in the sense that different platforms have different complementary roles within the structure. [5:36] For instance, the maritime helicopter's role is highly interdependent with its mother ship and the ship's actions and reactions can often depend on the helicopter's actions and the capabilities that it brings. Another example is the relationship between the frigate and the replenishment ship (AOR), where the ability of the frigate to do its job can be shaped by the availability of sustainment provided by the replenishment ship, or by the requirement to provide security and defence for the AOR. Conversely, the AOR's ability to fulfill its primary role can depend on the security provided by, or the disposition of the escort force which it is both supporting and by which it is being defended.

1.2.4 Self-organization

Self-organization is the ability of a system's agents to organize themselves from a state of apparent randomness into organized patterns of behaviour, without direction. It is an automatic response wherein agents self-synchronize, as opposed to having to be directed to act in a specific way. [3:22] This can be illustrated in the case where a helicopter screening ahead of a force detects a submarine. Force-wide pre-planned responses can be invoked based on the doctrine in effect. Without further order, additional helicopters and a Maritime Patrol Aircraft (MPA) could join the prosecution, a barrier may be established and the force could be manoeuvered to avoid the submarine.

1.2.5 Non-linearity

Non-linearity can be thought of as the unpredictability of a system's responses to changes or events. It can best be explained by referring to Edwin Lorenz's definition of linearity: "A linear process is one in which, if a change in any variable at some initial time produces a change in the same or some other variable at some later time, twice as large a change at the same initial time will produce twice as large a change at the same later time. You can substitute 'half' or 'five times' or 'a hundred times' for 'twice', and the description will remain valid."[5:14] Non-linearity implies that effects are not necessarily proportionate to changes. This can be illustrated by the example of the self-immolation of Mohamed Bouazizi, a Tunisian fruit seller as the triggering incident at the origin of the Arab Spring. [7]

2. DISCUSSION

2.1 The RCN as a CAS

2.1.1 Overview

While it is recognized that as an institution, the RCN is broader than its operational or warfighting organization, this discussion will focus on the operational aspects of the institution, nested in the current CAF operational construct.

The "Adaptive Fleet Literature Review" highlighted that the Navy is a CAS that has several different types of platforms and systems with complementary capabilities that are interconnected through a variety of communications pathways. The Navy is a system of systems composed of "thousands of personnel and systems performing a wide range of functions." [3:7]

The following discussion uses a simple fictitious conventional scenario of a frigate operating as part of the Canadian Task Group (TG) in a time of tension before hostilities have broken out. The multi-threat scenario illustrates the RCN as a CAS at different scales, interacting with the operational environment. The focus will be at the fine scale as this is the scale of highest complexity, which characterizes the complexity level of the entire CAS. [8:4]

2.1.2 Illustration of a CAS in a naval context

A frigate comprises many sub-unit teams, such as the operations team, damage control organization, and boarding party. Each of these sub-unit teams in turn are made up of personnel and equipment delivering discrete, complementary and mutually enabling capabilities. The discussion focuses on the Operations Team.

The frigate's Operations Team is composed of over 20 personnel organized into functional groupings representing Anti-Air Warfare (AAW), Anti-Surface Warfare (ASuW), Under Water Warfare (UWW), Information Management, Air Control, and Bridge Operations. These personnel monitor more than a dozen electro-optic, radar, sonar and electronic warfare sensors which feed into the operations room directly, or through the bridge. This sensor data is shared with the remainder of the force through more than a dozen tactical data links, internet-protocol based data, and voice networks. Externally this operations team is in communications with consorts, helicopters, maritime patrol and fighter aircraft, each with its own suite of sensors and weapons. Each feeds its information to the collective through the various networks, including to the task group command staff embarked in the flagship. The operations team is also linked to intelligence networks through the embarked cryptologic team. Complexity grows with the number of sensors available and the areas covered. It is logical to assume that more sensors and wider area coverage will yield more detections of contacts which need to be monitored or investigated (which prompt the CAS to react). Likewise correlation issues arise as sensors are networked and uncertainty exists relating to the identity of a given track.

Internally, the elements of the team communicate in order to share information and conduct the operation. Each of the operators has a degree of autonomy to interact with the environment and initiate actions. For example: an electronic warfare sensor operator is expected to initiate a response to what appears to him or her as a missile threat to the ship. This independent action engenders reactions within the ship and more than likely within the task group, as other units react to the operator's assessment and alarm, broadcast throughout the force. The force is then self-organizing in the sense that each unit will initiate a pre-planned response to the event based on its own understanding of its own circumstances. There is great interdependency within the operations room team and with the bridge as the response requires changes in equipment settings and manoeuver. The ideal manoeuvre response to the missile threat is compromised by a submarine threat which precludes maneuvering to the east. A prioritized compromise is reached. The ship is brought to action stations. In addition to interacting with external agents, the operations team now also interacts internally with an equally-complex damage control organization. Note that the agents act independently, but the system is self-organizing within the context of doctrine and the levels of control which are delegated. Although the response will generally conform to doctrine, it is not reasonable to expect linear response as circumstances will dictate specific actions. The situation proves not to be an attack, but a probe. During this probe, which came in under established commercial air lanes (driving the need to resolve the hostile from neutral or friendly air traffic), warnings were issued by a Task Group unit to the intruding aircraft. Probe profiles, including platform signatures, are recorded and the pre-planned responses are adjusted to the operating environment. Data that requires further analysis is pushed back through data networks to facilities ashore. Reports of the probe are passed throughout the Task Group and up the chain of command.

At the Task Group scale, the commander generally exercises command through the Composite Warfare Commander construct, delegating control over specific parts of the operation such as defence of the force from air or submarine threats to individual units. In this example, the Task Group comprises a command and control platform, a ship specialized in AAW, a replenishment ship, some frigates, and may have a submarine assigned [9:43]. The movements and reactions of the TG can be the result of the task group commander's decisions, a composite warfare commander's direction, or in the case of the previous example, the actions of one of the TG's units (in fact, one individual member of one of the ships).

In order to refine tactics for follow-on action, the adversary aircraft who conducted the probe records its observations regarding the composition of the force and its reaction to the intrusion. It feeds its own force's cycle of Observe, Orient, Decide and Act (Boyd's OODA loop).

The Canadian TG is operating within an alliance task force. The alliance's public affairs approach differs from Canada's. The probe event is characterized differently by the alliance and Canadian authorities. This creates a strategic issue where coherence of the alliance is questioned in the international media. The adversary force exploits this apparent contradictory public affairs stance in its efforts to shape the information environment.

The rift in the media prompts both the alliance and Canada to review their approaches to the characterization of interactions with the opposing force. New direction is passed to the tactical level to ensure strategic coherence of messaging.

2.2 Future Security Environment

2.2.1 Overview

This section draws primarily on the characterizations of the Future Security Environments (FSE) contained in The US National Intelligence Council's *Global Trends Paradox of Progress* [10]; and the UK Ministry of Defence's *Global Strategic Trends out to 2045*. [11] These highly complementary documents build on the Department of National Defence's own planning document: *The Future Security Environment 2013-2040* [12] and consistently highlight the emerging and expected security environment as highly complex system, containing innumerable agents and countless subsystems reflecting considerable uncertainty and non-linearity, which are expected to grow. The view is consistent with Ilachinski's who described armed conflicts in the CAS paradigm as being composed of diverse non-linear self-organizing agents who adapt to changes in an environment of decentralized control [3:35]. That characterization can be generalized to the broader FSE as the definitions of war and conflict seem to be evolving.

The modern security environment is extremely complex, containing a wide range of state and non-state agents. It should be underscored that "agents" are not limited to man-made phenomena, for instance typhoons or earthquakes could be termed agents.

In the FSE, non-linearity abounds, as Edward Lorenz observed: "…nonlinear systems have, for much of history, been considered nonsolvable…Unfortunately, nonlinearity is ubiquitous."[5:14]. Two examples illustrate non-linearity as a property of the security environment: all typhoons, by definition, have wind speeds over 64 knots, but not all typhoons gain strength or follow a trajectory that causes damage and devastation; and the previously-cited actions of Mohamed Bouazizi's actions as the trigger of the Arab Spring illustrates how a tragic, yet seemingly insignificant localized event can have monumental consequences in a highly interconnected world.

In a 2013 article, General of the Army Valery Gerasimov, Chief of the General Staff of the Russian Federation Armed Forces asserts that "the very "rules of war" have changed. The role of non-military means of achieving political and strategic goals has grown, and, in many cases, they have exceeded the power of force of weapons in their effectiveness" [13:24]. He goes on to describe how the methods of warfare have evolved from the traditional engagement of military forces against each other to far more complex methods, effectively blurring the distinction between peace and war. Key among the changes he describes are actions to undermine an opponent through the initiation of military actions in a peacetime environment; the destruction of critical civilian and military infrastructure through the use of precise means such as special forces, and the use of precision guided weaponry. He places great importance on mastering the information environment as an integral element of conflict and stresses the use of asymmetric warfare to achieve strategic aims: "…the use of special operations forces and internal opposition to create a permanently operating front through the entire territory of the enemy state, as well as informational actions, devices, and means that are constantly being perfected." [13:25]

Gerasimov's thoughts are echoed by the National Intelligence Council which sees an increased blurring of the lines between peace and war, to which it refers as the "gray zone" which states are likely to exploit. Through asymmetric means, state and non-state actors will exert pressure in order to foment instability and insecurity in their adversaries, but remain in the “gray zone”, short of provoking a state of open war by using techniques and non-military tools, which may not be readily attributed, therefore masking their actions through the use of proxies, or covert cyber-attacks or the use of special forces. Innovative use of social media and other high-speed electronic communications and an increase in the focus of operations in the information sphere are likely to continue, resulting in greater ambiguity and highlighting the need for accurate and timely information to support the decision cycle. [10:216]

2.2.2 Uncertainty stimulated by climate change, increasing population and urbanization

Climate change is expected to engender a rise in sea levels and an increase in the number and intensity of severe weather events with the potential to cause damage to coastal regions on a massive scale. [11:31] This in turn is likely to increase the demand for Humanitarian Assistance and Disaster Relief (HADR) missions, a common task for military forces. Occurrences of disasters will require flexibility to meet the demands of the mission. Increased frequency and severity of such events will place demands on the capacity of forces and could increase the concurrency of missions, perhaps driving demands for greater fleet size or specialization of HADR-specific capability.

The effects of climate change could be compounded by population growth and urbanization. Estimates of the growth of the world’s population range from 15% - 44% increases from current population levels by 2045. [11:3] This growth is expected to occur primarily in the less-developed, more unstable regions prone to stress and conflict. This is likely to exacerbate the situation and contribute to insecurity and instability. The growth of population, combined with the trend to urbanization will present additional challenges. The majority of the migration to urban centres will occur in the littoral regions of the world, indicating that additional stresses could manifest and where large populations would be at risk of climate-related natural disasters such as typhoons. [11:138]

In addition to the likely increase in frequency and scope of future HADR missions, the likely spread of unrest and conflict to overlap with natural disasters could pose significant obstacles to HADR forces. [11:31] Although humanitarian assistance is only generally provided with the consent of the host state, it is possible that the level of insecurity and conflict could exceed the host-nation’s ability to provide security for the humanitarian assistance effort. This would then prompt the requirement for the capability to provide security as an element of the response operation, placing broader demands on a response force.

Climate change is also likely to increase the accessibility of the Arctic as the polar ice cap recedes. This is, in turn, likely to spur increased economic activity and shipping. [11:39] The latter is of course of significant interest to Canada, where the Arctic domain is gaining importance and visibility.

2.2.3 Globalization increasing interdependence

The trend to globalization is likely to continue and the world's economies are likely to increase their interdependence and reliance on international trade. Reliance on commercial shipping is expected to increase markedly and so the prosperity and security of nations will also depend on the security of increasingly congested sea lanes. [11:50]

This interdependence adds to the complexity of the environment and will require adaptation. Protecting Canada is likely to mean protecting its supporting trade routes where they are most vulnerable. The implication is that the Navy could be called to protect shipping at choke points remote from Canada, requiring expeditionary capability to operate in littoral regions to protect the global shipping system either independently or, more likely as part of a broader effort. This is consistent with Gerasimov's notion of having to develop a system where defence of homeland national interests must be able to occur overseas. [13:27]

Banking and commercial systems are linked world-wide through the internet, creating additional interdependencies and vulnerabilities. The emergence of social media on a global scale has also increased the complexity of the environment and facilitated the broad dissemination of ideologies and airing of grievances in instantaneous real-time. Referring back to the example of Mohamed Bouazizi, social media as a tool of mass communication enabled the non-linear response to his self-immolation.

2.2.4 Greater diversity of agents and complexity

Complexity is likely to grow as the number and diversity of agents able to influence the security environment continues to expand. This will engender greater uncertainty and risk of conflict, including interstate conflict, as the number of states who develop the means to exert influence in the "gray zone" or through more traditional means of war continues to grow. [10:26]

The decreasing stability in failed and failing states and the spread of technology is likely to combine to produce an increase in non-state actors who have both the motivation and means to conduct terrorist acts. The terrorist threat is likely to become more diverse and difficult to counter owing to its broader number of sources and more varied methods. [10:41]

Private Military and Security Companies have emerged as a new kind of agent with significant potential to add complexity and instability to the environment. While they have frequently been contracted by state governments, agencies and militaries to fill gaps in their capabilities and capacities, their behaviours have often led to instability and backlash through unsanctioned actions such as: extra-judicial killings, torture and other civil rights violations, and human trafficking. Beyond their use by legitimate state actors, such organizations have also been linked to destabilizing events such as an attempted coup d'état in Equatorial Guinea in 2004 during which they acted out of their own self-interests. [14]

In addition to their more traditional roles, PMSCs have recently been used by states as covert proxies to exert destabilizing pressure without being linked directly to the action. Russia's actions in the Donbass region of Ukraine and in Syria are two recent examples of what is likely to be a continuing trend. [15]

2.2.5 Technological advances

Advances in technology, especially related to communications, computing and artificial intelligence are likely to have profound impacts on the Future Security Environment, causing greater complexity and uncertainty. [10:223] Technological advances prove a two-edged sword in the sense that they can be exploited by military and security forces to enhance their capabilities, but also can be used and adapted by adversaries to pursue their own aims.

Development of improved communications and computing can deliver rapid changes to the battlefield and generate enhanced threats. The trend towards a faster pace of technological change is expected to continue and accelerate, and advanced technology will become cheaper and more generally available. Two recent examples from the current conflict in Iraq illustrate the adaptation of terrorists to new technology and the attendant requirement for military force to be able to quickly adapt to that rapid innovation.

Terrorists and others can effect rapid change through the use of cheap modern technology. This is illustrated by the Islamic State of Iraq and the Levant's (ISIL, also known by its Arabic language acronym Daesh) use of commercially available small UAVs to deliver bomb attacks against coalition forces in Iraq. Countering this innovation required the rapid development and deployment of a defensive system capable of jamming these small UAVs [16:4].

The increasing proliferation of lethal autonomous strike systems such as remotely piloted aircraft and battlefield robots is also expected to change the environment. Because such systems reduce the risk to human life of the combatants who employ them, their proliferation is likely to increase the likelihood of armed conflict. [10:20]

ISIL has also been innovative in using existing technology in novel ways. They have modified commercial pattern freight and dump trucks into Armoured Vehicle Borne Improvised Explosive Devices (the so called "Mad Max" truck bombs) in order to breach coalition lines. This was initially highly effective until a suitable countermeasure was deployed. ISIL has also reportedly been working on development of "driverless" truck bombs. [17]

Clearly these adaptations of modern, widely available technology will likely continue to be exploited for nefarious ends in the future.

Attacks on the USS Cole in October 2000 [18] and on the French commercial taker Limburg off the coast of Yemen in 2002 [19], both attributed to Al Qaeda, are examples of terror attacks that used simple technology and suicide bombers. Since then opponents in a maritime context have made similar adaptations of ISIL's innovations. It has been assessed that the 30 January 2017 Houthi attack on the Saudi frigate Al Madinah was conducted by an unmanned surface craft, likely of Iranian origin. [20]

In addition to enabling unmanned vehicles, development in communications technology will enable faster and broader networking between agents and facilitate the decentralization of terrorist threats. More independent terror cells could acquire the means to gain better situational awareness and share this information across their networks. Better sensors and internet tools will assist them in identifying and exploiting vulnerabilities in their targets, enable the proliferation of terrorism, and complicate the counter terrorism effort. [10:41]

Advances in weapons technology, such as the fielding of directed energy weapons, [11:94] are under way and are expected to enter service with militaries in the near future. The impact of such developments is unclear; however, they will surely provide impetus for changes in weapons and platform designs in order to reduce their vulnerabilities.

Although these more sophisticated weapons are not likely to be widely available initially, they could proliferate to non-state actors and proxies, just as Hezbollah acquired C802 missiles, a sophisticated technology, which it used to conduct its attack on the Israeli corvette Hanit in 2006. [21]

2.2.6 Military and paramilitary threat to shipping

Given the increased complexity of the environment and the asymmetric approach taken by state and non-state actors alike, it can be expected that state and non-state actors will operate in the “gray zone.” Military forces could then be called to intervene to defend civilian shipping from threats aimed at destabilizing world, regional or national economies as a means of exerting pressures below the threshold of war (see section 2.2)

Examples can range from the innocuous 1995 Turbot War between Canada and Spain [22], where Spain dispatched warships to protect its fishing fleet from Canadian authorities, through current tensions in the South China Sea [23], to the more chilling example of the 1981-1987 Gulf “Tanker War.” An element of the Iran-Iraq war, the “Tanker War” saw over 450 ships from 38 countries attacked in the Persian Gulf. [24] This is the same conflict in which the USS Stark was attacked while performing escort duties. [25]

Given the increase in globalization and reliance on shipping, it is plausible that similar scenarios could emerge in the future and that Canada could be called on to protect merchant shipping in, or in proximity to some future conflict. Having noted the Hezbollah use of a sophisticated anti-ship missile like the C802 and Al Qaeda’s targeting of the Limburg by a less sophisticated improvised weapon, it is plausible that more shipping could be held at risk by non-state actors, or proxies of states not wishing direct confrontation or attribution of their actions.

2.2.7 Littoral issues

It is likely that maritime forces will increasingly be drawn into the littoral, in order to provide security within the maritime environment or to provide access and support to forces operating ashore. The notion of delivering forces from the sea, either to assist in HADR, or to conduct a combat mission, as was the case in Afghanistan after 9/11, or in the 1982 Falklands War, is grounded in historical fact. Analysis of the FSE indicates that such operations are likely to occur more often in a greater variety of locations, spurred by a broader variety of actors.

Bar-Yam uses the high complexity of the littoral “terrain” to distinguish it from the open sea. He speaks of the physical features of the littoral and its interface with the land mass. Beyond this coarse characterization lie the details which truly pose the greatest complexity and adaptability challenges for forces operating in the littoral. “The simplicity of the large scale ocean terrain is to be contrasted with the complexity at many scales of the littoral region... Complexity of the land-water interface arises both because of the natural features of this interface and because of the human aspects of population centers in the littoral region. [8:13] This means a broad range of agents add to the complexity of the littoral.

The traffic density in the littoral is caused by several factors, including the convergence of ocean-going vessels as they transit choke points, or approach the world’s ports. The “parking lot” of up to 150 ships at anchor off the port of Fujairah, U.A.E, [26] or the vessels at anchor on Constance Banks awaiting their turn to proceed to berths in Vancouver, 100 kilometres away, exemplify this. The littoral environment also contains large numbers of smaller, less conspicuous vessels which complicate the problems of detection and identification. Moreover, smaller, less conspicuous targets are more difficult to distinguishing from rocks or the coastline.

Navigation can be constrained by natural phenomena such as reefs, rocks or shoals, or by an opponent’s sea mines. Moreover, the littoral undersea environment is acoustically more far more complex than the open ocean due to natural effects of the sea-land interface, such as wave and tidal action on shoals and shoreline; the mixing of fresh water with sea water at the mouths of rivers (changing the acoustic properties of the water mass); larger numbers of noise-emitting boats and ships in proximity; and many other human activities such as urban noise and traffic, aircraft traffic, construction and other industrial processes that emit sounds contributing to raising the noise floor such as to make detecting and tracking targets (such as submarines) much more difficult.

The littoral electromagnetic spectrum is typically far more active than what is found offshore. The environment is flooded with commercial, private, marine, shore-based and airborne communications adding to the complexity. Greater concentrations of ships bring greater numbers of ship-board radars; the presence of coastal traffic management and surface and air search radars also complicate the environment.

Likewise the electro-optical detection problem is compounded by a greater density of elements against a background that is far more cluttered than the clear horizon of the open sea. Think of the difficulty of finding a small boat against the backdrop of city lights.

Operating in the littoral implies working in an environment of reduced time to react to any shore-based threats, thus requiring a compressed decision cycle (OODA loop). The topography of the shore line can mask the approach of a threat aircraft or missiles. Notwithstanding the details of Hanit’s readiness to detect the C802 that struck it, the example serves to illustrate the requirement for a ship operating in the littorals to have insight into what is going on ashore in order to ensure its survivability and mission success at sea.

In CAS terms, the littoral problem is summarized by Bar-Yam as a highly complex where: “enemies co-mingled with bystanders or friendly forces present high complexity challenges.” [8:3]

2.3 Implications of the FSE for the RCN

It is clear that the requirement for the Navy to exercise its current roles and missions will persist into the future, including a need for expeditionary capability to ensure security for Canada, and for its allies. The increasing complexity of the environment is likely to expand the roles that the RCN will play, particularly in the littoral. The trend toward a blurring of the lines between war, terrorism and criminality will continue to add complexity, likely engendering an increased focus on the more dense and complex littoral environment. This coupled with advances in technology likely to be exploited by state and non-state actors alike will require increasing levels of adaptability in order to succeed in meeting the emerging challenges.

In particular, the blurring of lines between war and conflict which exists in the “gray zone” just below the scale of war is an environment where a greater interagency effort will be required. As the diversity of antagonist agents in the security environment expands and diversifies, addressing issues and restoring security will require the cooperation of agencies with broader mandates than strictly defence. [12:99] It is likely that future security issues will have aspects requiring involvement of a multitude of other federal agencies and departments, in addition to allied military forces.

In addition to the ability to adapt its capabilities to a more complex environment, the RCN is likely to face greater demands on its capacity due to the increasing frequency with which natural disasters and other security-related events are likely to occur. The Capacity issues will need to be modelled. While the “Fleet Mix Study Iteration II” recognizes the changing future security environment [27:9], the impact of frequency and concurrency of missions on fleet size and mix requirements will need to be considered closely as the environment evolves.

Increasing complexity will drive the requirement for new capabilities to meet new and emerging threats such as small UAVs and directed energy weapons. Moreover, the likely increased need to operate in the littoral and its attendant pressures will increase. Conversely, the pace of technological advances poses an opportunity for the Navy, but requires adaptability and agility in order to benefit from what may be fleeting advantages. In a very simple example, the Navy must be able to adapt and find solutions to the Houthi attack on the Al Madinah, or what could be the littoral application of ISIL’s UAV or “Mad Max” boat. How do we best position the Navy to be able to rapidly respond to or exploit changes in technologies and withstand emerging threats, not only at the unit level, but at the system level?

The interconnectedness between its subsystems and therefore the Navy’s complexity relies on computer networks and long-haul communications requiring space assets, all of which have vulnerabilities. Consider a simple scenario where two sailors in two different frigates deployed together in the Black Sea are collaborating on a chat network. The two ships are operating within a nautical mile of each other, but the collaborative effort between these two sailors relies on satellites, and ground stations and network operations centres which could be located in Canada or elsewhere. The signal will have travelled thousands of miles to reach its destination only a mile away. This exemplifies the dependence that modern operations have on space capabilities. As technology evolves and the Navy is increasingly reliant on it for effective operations, is the Navy adaptable to operating in an environment where enablers such as reliable satellite communications are not available?

2.4 Force Structure and Force Generation

2.4.1 Overview

> "… This isn't going to be a one-time process of innovation. We won't just inject autonomy and all of a sudden it's going to be great for 40 years. This is going to be a tough competition—we're in a world of fast followers. We are a good, fast leader, but we should be prepared for operational and technological surprise. The force of the future is designed to get a force that is agile enough to adapt to surprise, because in the next 20 to 30 years, that may be endemic. We just don't know, and that is another aspect of the offset."
>
> -Robert O. Work
> Deputy Secretary of Defense [28:7]

Following the principle of "form follows function," the aim of force structure is to deliver on the strategic intent, shaped by the Future Security Environment. The Force Development process needs to answer the questions – what capabilities do we need, and how to organize ourselves to deliver on the mission/strategic intent?

Framing the future security environment in the CAS paradigm highlights the need for the RCN to be adaptable in the future. This is recognized as an important element of the RCN's Executive Plan. [9:33] As highlighted in the preceding section, the FSE will likely place less predictable and more varied demands on the RCN to respond to world events. The demands on existing capabilities will grow and technology is likely to be a driver of change, requiring the fielding of new capabilities within the fleet.

2.4.2 Force Development

In his paper, Murphy highlights that the use of scenarios as a basis of capability planning may be limiting by not examining the full range of possibilities, nor factoring concurrency, uncertainty or evolution. In his words, relying on scenarios "…creates a class of unexamined risk and increases the potential for surprise." [5:69] DND's process as documented in the *Capability Based Planning Handbook* acknowledges this limitation and stresses that the intention is for planners to use the scenarios as the basis for capability requirements and that "…the capabilities to be developed require an inherent flexibility for adaptation…" [29:7]

Can adopting a CAS approach help to more heavily weight the adaptability factor in any given articulation of required capability? Given the complexity, diversity and interdependence of the force, is there a way to measure the aggregate system capability of the RCN? Can we find a way to factor in greater uncertainty into the force development process?

The RCN has used the Fleet Mix Study II and its Tyche Model to derive fleet configurations, each with an associated level of strategic risk. It uses vignettes (scenarios) and draws on historical evidence to weigh the relative chance of a given task arising, requiring a given capability set. It provides a coarse distinction between the different platform types and their capabilities. Adopting a CAS paradigm could be complementary to the Fleet Mix Study's approach in that the CAS approach would be forward-looking and anticipatory. It could also take into account concurrency of tasks and factor in possible attrition. While Tyche can run multiple missions at once, it is not designed to run multiple taskings within the same mission, nor does it factor in attrition. [27:9]

The attrition problem is especially conspicuous. A fleet can suffer attrition not only from combat losses, but from accidents, equipment failures due to aging processes, or non-availability due to maintenance requirements. The problem of attrition is especially accentuated when dealing with a small number of aging platforms, as recent experience has shown. It can be argued that the adaptability of a system such as the RCN should factor attrition as a consideration. The September 2014 decision to retire four of the Navy's major warships due to age and accidents illustrates the point. How did the reduction by 23.5% of the RCN's major surface warship fleet, including its entire ability to replenish at sea, translate into the reduction in complexity and adaptability of the RCN, and risk for Canada?

Accepting a complex future security environment and trends that would lead us to expect greater complexity and uncertainty in that future, how would we articulate a requirement for adaptability as a capability area?

2.4.3 Adaptable fleet

It can be argued that past experience has demonstrated that the RCN is an adaptable organization, at least at some levels. Ships already at-sea have been re-tasked numerous times to conduct operations which had not been considered before they sailed. This adaptability ranges from re-tasking for missions that are aligned with the baseline capability, but adapted to a specific environment, through the use of mission–specific work ups, or staff assisted visits – an example is the chemical defence training that OP APOLLO ROTO ZERO received while en route to the North Arabian Sea. Likewise, short notice tasking in OP MEGAPHONE in 2000 saw the air detachment of HMCS Iroquois conduct a helicopter insertion of the boarding party onto the motor vessel GTS Katie. This method of boarding party insertion was not a current practice at the time.

The RCN's adoption of the Helicopter Air Detachment (HELAIRDET) concept is an example of a more complex adaptation, where the technical and procedural grooming and working up of a ship and its twinned HELAIRDET are more complex and protracted events. This has been effective in enhancing the ships' overall warfighting and logistic capabilities with the Sea King and will provide for the deployment of far greater capabilities as the Cyclone helicopter is fully introduced to the fleet.

Mission fits to keep pace with the emergence of networked operations at the turn of the century frequently saw teams adapt to the new capability in innovative ways such as the use of multiple laptops placed atop ship standard display consoles in operations rooms. Likewise, space was carved out of equipment spaces in an ad hoc way in order to accommodate new capabilities such as the Cryptologic Direct Support Elements, or the Scan Eagle UAV system embarked for OP METRIC. [30] The latest example of this mission fit modularity is the development of the enhanced boarding capability offered by the Maritime Tactical Operations Group (MTOG). While these fits met operational requirements, they often came at the expense of crew comfort or degradation in some other capability area.

With the exception of the HELAIRDETs, the preceding examples highlight adaptability through mission fits – what can be termed ad hoc modularity. The conversion of four modernized Halifax class frigates to be configured as interim command and control ships was inserted into the mid-life modernization programme as an emerging fleet requirement, in relief of the then-aging Iroquois class destroyers. This example of adaptability reflects seizing an opportunity in the modernization programme to squeeze in additional capability, but to some extent it has also eaten into the comfort of the flagship crew.

In contrast to these retro-fit issues, which generally involve some kind of trade-off, the Kingston class design incorporated the concept of containerized mission modules. Another, more recent example is that of the Cyclone helicopter which is being delivered with the ability to reconfigure the aircraft cabin to a utility and troop transport role, thus delivering adaptability and flexibility as a component of the capability.

An ideal force structure would see a fleet of unlimited capability and capacity; however this ideal clashes with the realities of available resources, and therefore gives rise to the need for flexibility and trade-offs in terms of capability, capacity and cost. This is a fundamental question which is at the heart of the future force planning effort. Given finite resources, where is the solution space that satisfies a level of ambition while enabling risk to be brought within acceptable limits? The CAS paradigm could potentially be applied to help establish the risks, particularly associated with complexity and adaptability.

2.4.4 What is the best way to structure the fleet to be adaptable?

Given that a navy is a "…series of 40- to 50-year investments" [9], the fundamental question for force developers is how to structure the force to be adaptable over such a long time frame? Is it better to build more specialization or greater adaptability at the unit scale?

The range of options spans building more capability, concentrated into future major platforms such as the Canadian Surface Combatant (CSC); building a greater diversity of smaller specialized platforms, which could be cheaper (as was the intention with the USN's Streetfighter concept, which was abandoned in favour of Littoral Combat Ship); or adopting modularity concepts in order to adapt to changing mission requirements. Which of these paths would best support the delivery of future capability? Intuitively, building more capability into a platform is likely to drive up its cost, which is likely to limit the number of combatants that can be fielded within resources. The notion of cheaper, smaller, more numerous specialized platforms is likely to be illusory, or pose a moral dilemma: ships will have to have the ability to deploy to where they are needed and to either have the ability to protect themselves, or be protected by more capable ships. It is unlikely that the Navy would task a manned platform to operate in an environment where its own security could not reasonably be assured. [31:3-8]

Two allied navies provide examples of the concept of modularity, as a means to adapt units to missions. The Danish Navy developed its Standard Flex (STANFLEX) concept in the 1990s and has applied it across the fleet as an effective way to enhance the baseline capabilities of ships by swapping in and out modular containerized capabilities. Since the ships and modules were designed as a system, reconfiguration is a relatively simple and efficient process. [32] These ships, such as the Absalon class, have deployed to expeditionary theatres, alongside Canadian Ships, including as flagship of CTF 150 in 2008. [33]

The US Navy's littoral combat ship takes a similar approach, with a baseline fit for its own self-defence and mission modules for specialized capabilities such as Surface Warfare, Anti-Submarine Warfare and Mine Warfare. [34] Both Absalon and the LCS have space on board to host additional personnel to support special operations or other activities.

We thus have examples of modularity being adopted to provide flexibility and adaptiveness to navies of different sizes - the large USN and the Danish Navy, which is more comparable in size to the current RCN fleet. All three navies operate on a global scale, and all three have large homeland ocean areas of responsibility. [35]

Regardless of the extent to which modularity is adopted into any fleet programme, it is clear that it is important to build flexibility at the outset of any ship project. [36]

Advances in computing power, communications and artificial intelligence are facilitating the development of unmanned vehicles. Unmanned aerial vehicles (UAV), of differing size, endurance and capabilities are now commonplace. Some of these, such as the Scan Eagle UAV, have already been successfully adapted to Canadian frigates as mission fits. [30]

The RCN currently makes extensive use of the "Hammerhead" unmanned surface vehicle (USV) as a training target for surface warfare. [37] The USV is used to simulate hostile fast attack craft in defensive scenarios. The potential use of USVs for discrete reconnaissance, insertion or extraction and recovery, or interdiction operations in the littoral environment could be explored.

Likewise, the use of USVs by potential hostile forces as remotely piloted bombs will pose threats that will need to be countered. As discussed earlier, the Houthi attack on the Al Madinah using an unmanned surface vessel highlights that emerging technology continually presents new problems to address.

Unmanned Undersea Vehicles (UUVs) currently range from relatively simple Expendable Mobile ASW Training Targets (EMATT) [38] to complex mine-hunting systems. The USN's Littoral Combat Ship's Mine Warfare module includes a UUV. [34] DRDC's development of the Dorado semi-submersible vehicle for the Remote Minehunting System is another example of a more complex UUV.[39]

It is clear that unmanned vehicles are already a part of the naval toolbox. One of the key opportunities that this emerging technology represents is an ability to network many autonomous vehicles together to deliver the desired effects. Murphy describes the USAF concept of networked swarms of UAVs, controlled by few humans. [5:45] This is another example of the increasing complexity of the environment and of modern military forces.

2.4.5 Acquisition considerations

Setting aside programmatic considerations and the National Shipbuilding Procurement Strategy as being beyond the scope of this discussion, it is important to underscore that the security environment drives requirements at a rate which outpaces the acquisition cycle. Thus, it can be reasonably expected that new bona fide requirements will emerge over the life of a ship project, and certainly over the service life of a platform.

While, as discussed at Section 2.4.2, the RCN has been successful in adapting to new mission requirements and new technologies; those adaptations have come at both incurred and opportunity costs. What is not captured in this discussion is the level of effort, complexity and cost which have enabled the ad hoc approach to adaptability, either through mission fits, or retro-fits of ships which had little or no margin for growth. In terms of being able to adapt to the requirements of an evolving environment, and to exploit advances in technology, consideration should be given to prescribing adaptability and flexibility into acquisition projects. The ability to insert new and emerging technology into new ship programmes should be pursued.

System-wide flexibility and adaptability may be enabled by requiring sufficient margin for growth, in order to more readily retro-fit capability into future platforms. Likewise adopting a modular approach, as previously discussed, could provide some measure of flexibility. The critical decisions to be made will revolve around what are a platform's baseline "core" requirements and which capabilities can be delivered through a modular approach. Applying the CAS construct may assist in determining how capabilities are bundled. What is the best way to group capabilities (agents) into platforms or modules (subsystems) and arrange the subsystems and their interdependencies to maximize overall system effectiveness and adaptability?

Consideration should be given to a continual build programme in order to avoid the peaks and troughs in the RCN's capacity profile. The practice of building ship classes in compressed time lines may have programmatic advantages such as benefiting from shipyard learning curves, but it exposes the RCN as a system to the risk of attrition due to obsolescence. For instance, the twelve Halifax class frigates were commissioned within four years (51 months) of each other. This in turn meant that they reached mid-life in a similarly compressed time frame. In the end, the (highly successful) Halifax Class Modernization saw twelve ships taken out of service over seven years, with significant impact on fleet capacity. In addition to the many organizational changes which were required to effect the de-activation and re-activation of such a large portion of the fleet in a compressed time frame, the reduced capacity also required innovations such as HMCS Toronto's 2013 crew swap in Kuwait in order to meet RCN commitments. The downstream attrition impact inherent in the compressed batch acquisition of the Halifax class was compounded by the same phenomenon occurring in the Iroquois and Protecteur classes as the Navy opted to retire them due to obsolescence issues in September 2014.

Finally, a continual build would enhance adaptability and robustness of the system by maintaining an industrial base which could react to emerging requirements.

2.4.6 Basing and Infrastructure

There are no indications in the future security environment that would indicate a requirement for the Navy to make significant changes to the bases and infrastructure beyond those already being planned for Halifax and Esquimalt. However, a major “Black Swan” (surprise, large impact) event could have disruptive consequences. The most likely of these would be the effects of a major crustal or subduction zone earthquake near Esquimalt.

As far as forward-basing goes, the RCN has shown impressive flexibility and adaptability in the past. The Forward Logistic Site concept is well-developed and the RCN has repeatedly successfully sustained ships in operational theatres for prolonged periods, including conducting complex maintenance periods alongside in foreign ports, and the crew swap of HMCS Toronto in Kuwait.

The emergence of the Arctic as an area of increased interest, traffic and resource exploitation over the next decades will drive the requirement for surveillance and presence capabilities in Canada’s North and may highlight requirements for a response capability which could involve basing beyond the austere naval facility at Nanisivik. The imminent entrance into service of the Arctic Offshore Patrol Ship is well-timed to deliver presence and knowledge of that vast expeditionary area of operations at the leading edge, if not in advance of the expected increased activity.

While climate change is not the only driver of activity in the Arctic, it is one which likely will yield the greatest uncertainty. While exploitation of the Canadian Arctic’s mineral resources has traditionally often stimulated ship traffic, this has been highly predictable, with the possible exception of this year, where the iron ore mine at Mary River raised a requirement to conduct a sealift operation outside the usual navigation season. That being said, this event follows a deliberate regulatory process that is well known. [40]

2.4.7 Doctrine and lessons learned

Related to adaptability, much of the focus of the CAS paradigm centers on how agents interact both within their own system and with their environments. In the context of military operations, the CAS paradigm may be applicable to developing an approach to speeding decision making process and accelerating the OODA loop by exploiting greater agents (as sensors and actors) interconnections and processes. Referring back to the example of the frigate operations team in Section 2.1, engaging the force OODA loop with that of the adversary, and the notion of distributed control as a means to speed adaptability and decision making are two areas where a CAS framework may yield benefit. The discussion rapidly spills over into Command and Control. Although Command and Control is beyond the scope of this paper, this is an area where CAS theory and modelling may have significant impact.

Can CAS help to develop means of speeding the adaptability of the force, by focussing on the interconnected information pathways and the fostering of self-organization, in the multi-agent, multi-communications pathway environment of naval operations?

Similarly, can CAS assist in evolving Command and Control constructs and more effective delegation of control in order to accelerate decision–making?

A CAS approach to the evolution of information management has the potential to inform decisions, particularly regarding advances in communications and sensor technology. Harnessing and making sense of the vast amounts of information which will be available at the unit or task group levels runs the risk of overwhelming current systems and practices. Can the CAS paradigm inform decisions on the information management processes which underpin decision making and effectiveness of the force?

Focusing on adaptability as a capability and the ability to gather, disseminate and rapidly incorporate lessons learned is an area which is likely to be fertile in the context of the CAS framework.

2.4.8 Force Generation

It can be said that the RCN has been an adaptive organization. Its tiered readiness programme has delivered on fleet requirements, setting a baseline upon which to build and tailor additional capabilities. As discussed earlier in this paper, the deployment of mission-fitted equipment and tailored training in the form of mission-specific workups has resulted in successful deployments, albeit with constraints on habitability and in some cases inadequate training and support documentation for new systems. In these instances, RCN personnel relied on initiative and cooperating forces to gain the necessary operational and technical knowledge. In the network information age, with the capability to reach back, consideration should be given to improving how training and documentation is delivered.

Major training elements of force generation involve complex exercises in simulated threat environments. Successful work up and Operations Team Training (OTT) are generally fine examples of adaptability and anti-fragility. Although these are training events, there is significant stress on the individuals and the system as a whole. In any given work up or operations team training scenario, the multitude of agents who can do exactly the right or wrong thing at any given time is daunting and the impacts of individuals' actions are non-linear. The contrast between the self-synchronization and effectiveness of teams at the beginning of a work up/OTT and those who complete the events successfully is generally striking. The complexity of this type of training events may be an area where the CAS paradigm might have high impact. Can the CAS paradigm assist in speeding the learning and adaptation in training? Can we be confident that the anti-fragility that is repeatedly demonstrated in complex training events will be replicated in operational and combat situations?

Similarly, applying the CAS paradigm to constructing scenarios in the Task Group Force Integration Training and applying the CAS framework to the TG Command and Control and Information management doctrine could be instructive. Although the stereotype of a military organization is that command is highly hierarchical, control is frequently delegated. Moreover, notwithstanding the formal hierarchical structure, it is likely that most commanders have at some point found themselves having been bound to a given course of action as a result of decisions being made or actions initiated at very low levels, whether or not the action was within the bounds of delegated control (a very simple example of undelegated control would be the immediate execution of an incorrect manoeuvering signal being sent by a junior operator).

Operations Research drawing on the CAS framework is likely to support better decision-making on deployed operations and complex exercises. Addressing surveillance issues or ASW search optimizations are areas where the CAS framework would apply.

The CAS paradigm, in light of the emerging FSE shaped by rapid advances in information technology and socio-economic change, has the potential to inform approaches to foster adaptability at the individual level. If we think of adaptability as a capability, then what are the implications for the screening and selection of recruits into the force? Are there implications on the way that careers are managed, particularly in the progression to ship command and beyond?

The expected rapid pace of technological change and the blurring of the edges of war as described by Gerasimov [13] portend the increased use of information operations and warfare via other means, which may require different skill sets and career paths. The CAF is already moving on the creation of a cadre of cyber warriors and has considered different force recruiting and generation models. What are the other highly specialized skill sets that the Navy will require in order to enable it to adapt to emerging requirements?

If modularity is the principal path through which to deliver diversity and therefore flexibility, as appears to be the case, [9:35] then what implications will that have for the sustainment of the capability, the training, career path and operational tempo of personnel, and crewing concepts for the future fleet?

2.4.9 Modelling and Simulation

With a few exceptions, the military applications of CAS to modelling and simulation referred to in the Adaptive Fleet Literature Review tend to be land-centric; however, it is clear that the framework could be useful in helping inform the RCN's force development decisions and to enhance its force generation and employment. What is not clear is the level of effort that would be required to model the agents to sufficient fidelity to provide useful results.

Bar-Yam's application of Multiscale Complex Systems Analysis to the littoral environment provides an interesting avenue for further investigation. [8:10-26] This could be useful in modelling different agents at the fine scale (ships, boats, manned aircraft, or unmanned platforms to act as sensors and effectors); to examine networked control structure options; and to inform large scale force capability and structure suitability for the complex environment. Again, the modelling at the agent level is likely to need a significant effort to reach a fidelity required to inform force structure decisions.

From a force development perspective, adopting a CAS framework would be complementary to the Fleet Mix Study II approach by attempting to qualify the adaptability that any given fleet mix provides at the large scale level. This should include incorporating attrition and concurrency of taskings within missions as two variables or stresses to which given fleet mixes are exposed.

Modelling and simulation could assist in helping to better define adaptability requirements for future capabilities at all scales from finest level (which could be below the platform level) to large scale system level (i.e.: fleet mix options).

In addition to assessing a given force structure in the traditional context of the inherent capabilities it delivers, Murphy suggests (without detailed elaboration) assessing force structures using four inter-related measures of performance; which he defines as follows:

a. Diversity - the extent to which a force is "…composed of distinct or unlike elements or qualities."[5:32]
b. Flexibility - a force's "…capacity to accommodate or respond to a variety of scenarios."[5:79]
c. Robustness - the "sensitivity to changes in itself (including those an adversary induces)." [5:80]
d. Adaptability – a force's "...capacity to change its composition over time in response to changes in the environment." [5:81]

While these may be a good starting point from which to develop measures of performance, more work is required in this area. These proposed measures of performance also serve to illustrate two of the difficulties inherent in adopting the CAS framework. The first point is that Diversity, Robustness and Adaptability were introduced in sections 1.2.1 and 1.2.2 of this paper with slightly differing definitions indicates that the taxonomy is not yet settled in this evolving field of study. The second point is that the inter-relationships between these qualities are such as to almost make their discussion circular, and certainly esoteric.

The adoption of modelling tools and simulation based on the CAS framework could potentially yield significant benefits in the conduct of complex training environments such as work ups, Operations Team Training and Task Group Force Integration Training. These highly complex events are focussed on building the self-organizing and anti-fragility characteristics of the teams and enhancing the team dynamics and interrelationships so as to improve the speed and quality of response to stress and decision making. This also indicates the potential to help shape and support the development of better command and control in a networked operating environment.

Finally, it is apparent that modelling and simulation using the CAS framework could play a significant role in supporting the Orientation, COA Development and Plan Review stages of the Operational Planning Process.

3. CONCLUSION

Notwithstanding that the military applications of CAS theory have primarily been nested in the land environment, it is clear that the CAS paradigm has the potential to inform and support RCN decision making in the areas of the development, generation and employment of the naval force.

Viewing projections of the future security environment through the lens of the CAS paradigm reinforces the notion that the world is becoming increasingly more complex, non-linear and uncertain. That increased complexity, stimulated by such factors as the increasing pace of technological change, climate change, globalization and demographic change, will in turn drive the requirement for military forces to be more complex and adaptive in response to those stresses. The implications are that the RCN of the future is likely to require a broader set of evolving capabilities and will be called upon to exert influence close to home and overseas in littoral zones of instability as well as upon the high seas in order to counter conventional and to an increasing degree, sophisticated asymmetric threats. The RCN will need to evolve its complexity and increase its adaptability to meet the challenges of the FSE.

Although CAS is a paradigm which has emerged relatively recently, adopting the CAS framework as an element of force planning does not represent a bold course alteration for the RCN, as the notions of complexity and adaptability are incorporated into *Leadmark 2050*. [9:58] The CAS paradigm can help to inform force structure decisions by focusing on complexity and adaptability as necessary attributes at all levels ranging from the finest scales (below the unit level) to the large scale system that is the Navy. This more focused approach to adaptability and complexity would complement the existing analysis embodied in the *Fleet Mix Study II*, with the potential to enhance the RCN's readiness to deal with the vagaries of the FSE over the long term.

CAS should be able to assist in developing the options through which complexity and adaptability can be delivered - whether through highly complex multi-purpose ships and aircraft, through a greater number of specialized platforms, through modular concepts, or through a combination of the three. The CAS approach should lead to better informed decisions regarding the force-level cost-capability-capacity trade off which is necessary in an environment of finite resources.

It is apparent from this review that the CAS framework has significant application to Command and Control and decision making processes. This aspect warrants more detailed examination.

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